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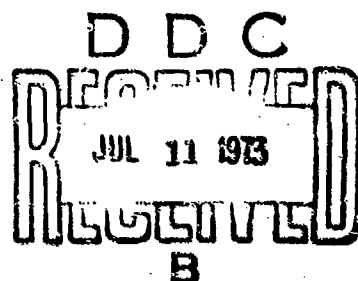
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# FREE RADICAL FILM HEAT PROCESSOR

M. D'AQUINO

Fairchild Space and Defense Systems  
Division of Fairchild Camera and Instrument Corp.  
Syosset, New York

June 1973



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AIR FORCE AVIONICS LABORATORY

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AIR FORCE SYSTEMS COMMAND  
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## FOREWORD

This Final Report was prepared by the Fairchild Space and Defense Systems (FSDS) Division of Fairchild Camera and Instrument Corporation at Syosset, New York, under Contract No. F33615-72-C-1420, task USAF 0003, FSDS Project Number 2772. The work was performed under the direction of the Air Force Avionics Laboratory, Reconnaissance and Surveillance Division, Photographic Branch; Mr. James R. Pecqueux (AFAL/RSP) was the project engineer for the Air Force.

The development of the Free Radical Film Heat Processor was conducted from December 1971 through March 1973. Appreciation is expressed to Mr. J. Pecqueux (WPAFB) for his continued suggestions throughout the program.

This report was submitted by the author in May 1973.

This technical report has been reviewed and is approved.

  
\_\_\_\_\_  
A. W. Berg, Chief  
Recon Sensor Dev Branch  
Recon & Surveillance Division  
Air Force Avionics Laboratory

## ABSTRACT

Development of a Free Radical Film Heat Processor provided an accurate test bed for the determination of processing requirements for Free Radical Film Materials. The device consists of two units: a Processor and a Fume Scrubber. The Processor permits film rolls, ranging from 70mm to 9.5 inches wide, to be subjected to any desired processing temperature between 100 to 170°C at processing speeds from 5 to 100 feet per minute. At 25 feet per minute the 75 foot processing film path length permits a three minute processing time. Film tension can be controlled when processing at 25 feet per minute or less at any incremental setting between 0.25 to 1.25 pounds per inch of film width. Additional capability allows high speed film transport between 25 and 100 feet per minute. Processing byproducts emitted by the Free Radical materials are filtered and almost completely removed from the hot processing air by an aqueous fume scrubber.

The equipment will be used to test and evaluate Free Radical and other heat processed duplication films. It will also provide design criteria for the development of any necessary second generation processors.



## TABLE OF CONTENTS

Section	Title	Page
1	INTRODUCTION AND OBJECTIVES . . . . .	1
1.1	SCOPE OF EFFORT . . . . .	1
1.2	PROGRAM OBJECTIVES . . . . .	1
1.3	GENERAL BACKGROUND . . . . .	1
2	PERFORMANCE REQUIREMENTS . . . . .	3
2.1	HEAT CHAMBER . . . . .	3
2.2	TRANSPORT SYSTEM . . . . .	3
2.3	FILTERED EXHAUST SYSTEM . . . . .	4
2.4	HEAT PROCESSOR . . . . .	4
3	SYSTEM DESCRIPTION . . . . .	5
3.1	GENERAL DESCRIPTION . . . . .	5
3.2	SYSTEM SPECIFICATIONS . . . . .	10
4	FILM TRANSPORT SYSTEM . . . . .	13
4.1	FILM PATH . . . . .	13
4.2	CAPSTAN DRIVE . . . . .	16
4.3	TENSION SUPPLY STAGE . . . . .	18
4.4	FILM SUPPORT ASSEMBLY . . . . .	19
4.5	FILM TAKE-UP STAGE . . . . .	19
4.6	END OF FILM SENSOR . . . . .	22
5	TEMPERATURE CONTROL SYSTEM . . . . .	25
5.1	CONTROLLERS . . . . .	25
5.2	SYSTEM HEATERS . . . . .	28
5.2.1	Intake Air Heaters . . . . .	28
5.2.2	Chamber Wall Heaters . . . . .	31
5.2.3	Air Bar Heaters . . . . .	31
5.2.4	Pre-Heat Roller . . . . .	32
5.3	TEMPERATURE UNIFORMITY . . . . .	34

## TABLE OF CONTENTS CONTINUED

Section	Title	Page
6	AIR FLOW SYSTEM .....	35
6.1	FLOW ANALYSIS .....	35
6.2	FILM HEATING .....	42
6.3	FILM COOLING .....	45
6.4	VARIABLE AIR FLOW .....	46
6.5	AIR BAR .....	46
6.5.1	Air Flow Analysis .....	47
7	AIR FILTERING SYSTEM .....	53
8	LUBRICATION CONSIDERATIONS .....	57/58
9	ACCEPTANCE TESTING .....	59
9.1	ACCEPTANCE TEST RESULTS .....	59
9.2	CONCLUSION .....	60
9.3	RECOMMENDATIONS .....	61

## LIST OF ILLUSTRATIONS

Figure	Title	Page
1	Model F-1001 Free Radical Film Heat Processor . . . . .	6
2	Model F-1001 Free Radical Film Heat Processor . . . . .	7
3	System Flow Block Diagram . . . . .	8
4	Control Panel . . . . .	9
5	Film Transport System Block Diagram . . . . .	14
6	Film Threading Diagram . . . . .	15
7	Film Support Roller Assembly . . . . .	20
8	Roller Design . . . . .	21
9	Temperature Control System Block Diagram . . . . .	26
10	Pre-Heat Roller Schematic . . . . .	33
11	Air Flow System Block Diagram . . . . .	36
12	Air Flow Analysis Schematic . . . . .	39
13	Air Flow Path Across Film . . . . .	44
14	Air Bearing Analysis Schematic . . . . .	48
15	Pressure Required Between Air-Bar and Film . . . . .	50
16	Volume Rate of Flow Required Between Air-Bar . . . . . 51/52 and Film	
17	Fume Scrubber Block Diagram . . . . .	54

## LIST OF TABLES

Table	Title	Page
I	Pressure Drop Matrix . . . . .	43

## SECTION I

### INTRODUCTION AND OBJECTIVES

#### 1.1 SCOPE OF REPORT

This Final Report describes the technical efforts carried out by Fairchild Space and Defense Systems, a Division of Fairchild Camera and Instrument Corporation, for the development of a Free Radical Film Heat Processor authorized by USAF Contract No. F33615-72-C-1420 dated 01 December 1971.

The report is divided into 9 sections. Section 1 summarizes the objectives of the program and presents brief background data. Sections 2 through 7 contain technical descriptions and analyses of the design. Section 8 reports the results of final acceptance tests, while conclusions and recommendations are reported in Section 9.

#### 1.2 PROGRAM OBJECTIVES

Program objective was to design, fabricate, test and deliver a heat-processor consisting of a heating chamber, a film supply/transport/takeup system, and a filtered exhaust system within an appropriate enclosure assembly. Of major importance was the need to realize a processor that would provide a means for consistent, repeatable precision processing conditions for evaluation of the sensitometric and image retention properties of films such as Photo Horizon, Inc., Free-Radical duplication films.

#### 1.3 GENERAL BACKGROUND

A duplicating/processing system which will eliminate the inherent disadvantages of the conventional silver develop-fix-wash method of image duplication is desired by many user agencies. This system must be capable of retaining extremely fine detail, permit accurate and rapid visual interpretation, reduce the requirements for large volumes of chemicals and water, and reduce the consumption of silver metal resources. A photo-sensitive product potentially capable of satisfying the above need has been formulated by Horizons Inc., Cleveland, Ohio. The product is a non-silver, Free-Radical photo sensitive coating on a standard mylar base material. After being properly exposed, image densities are developed and fixed by the application of heat, thus eliminating considerable logistic support and time consuming develop, fix, wash and dry requirements.

Test and evaluation of the Free- Radical heat processed photographic duplicating material has been seriously restricted by the lack of a high precision and flexible heat application and film transport system which would permit consistent and uniform processing of sensitometric samples and full rolls of duplicated imagery. The need, therefore, existed for a heat-processing capability which would enable complete and accurate evaluations of present day Free-Radical type emulsions and become a basis for the design of operational equipment if the heat processing method becomes the replacement media for conventional wet-silver materials.

## SECTION II

### PERFORMANCE REQUIREMENTS

This section itemizes the performance requirements of the Heat Processor.

2.1 Heat Chamber - allow operator selectable temperature control over a range of 100 to 170°C. Temperature control system must provide for and maintain any setting to within  $\pm 1^\circ\text{C}$  at the film surfaces, over the range of film widths from 70mm to 9.5 inches, and base thicknesses of from 0.003 to 0.0055 inch. Proportional temperature controllers are to be employed with self sustaining features to enable control over maximum changes of thermal load related to film transport rates.

Temperature control must operate under surrounding ambient conditions of 50 to 100°F and 20 to 90 percent relative humidity.

Film path length in chamber must provide for at least three minutes of temperature processing at a transport rate of 25 feet per minute.

#### 2.2 Transport System

- Provide for the feed, transport, and takeup of Free Radical material in widths from 70mm to 9.5 inches and in lengths up to 1,400 feet of 4-mil base film on 10.5 inch diameter spools.
- Provide variable longitudinal film tension over the range of 0.25 to 1.25 pounds per inch of film width with proper tracking and transport.
- Continuously adjustable speed over the range of from 5 to 100 feet per minute. Speed to be maintained to within  $\pm 1\%$  of the selected speed.
- When film is above 50°C, no contact with the transport system must occur on the film emulsion.

### 2.3

#### Filtered Exhaust System

- Filtering system is to remove film processing by-products from processing chamber.
- A negative pressure is to be maintained in the processing chamber to prevent leakage of both toxic vapors and particles which could cause a potential health hazard or contaminate a clean room environment.
- The filtering system is to remove from the exhausting air any toxic vapors and particles which could pollute the environment.

### 2.4

#### Heat-Processor

- System accuracy of all dynamic indicating devices shall be such that the sum of their errors will not be a cause of out-of-tolerance heat processing characteristics.
- Self-controlling features are to maintain pre-set processing conditions within specified tolerances throughout operating periods of six hours.

## SECTION III

### SYSTEM DESCRIPTION

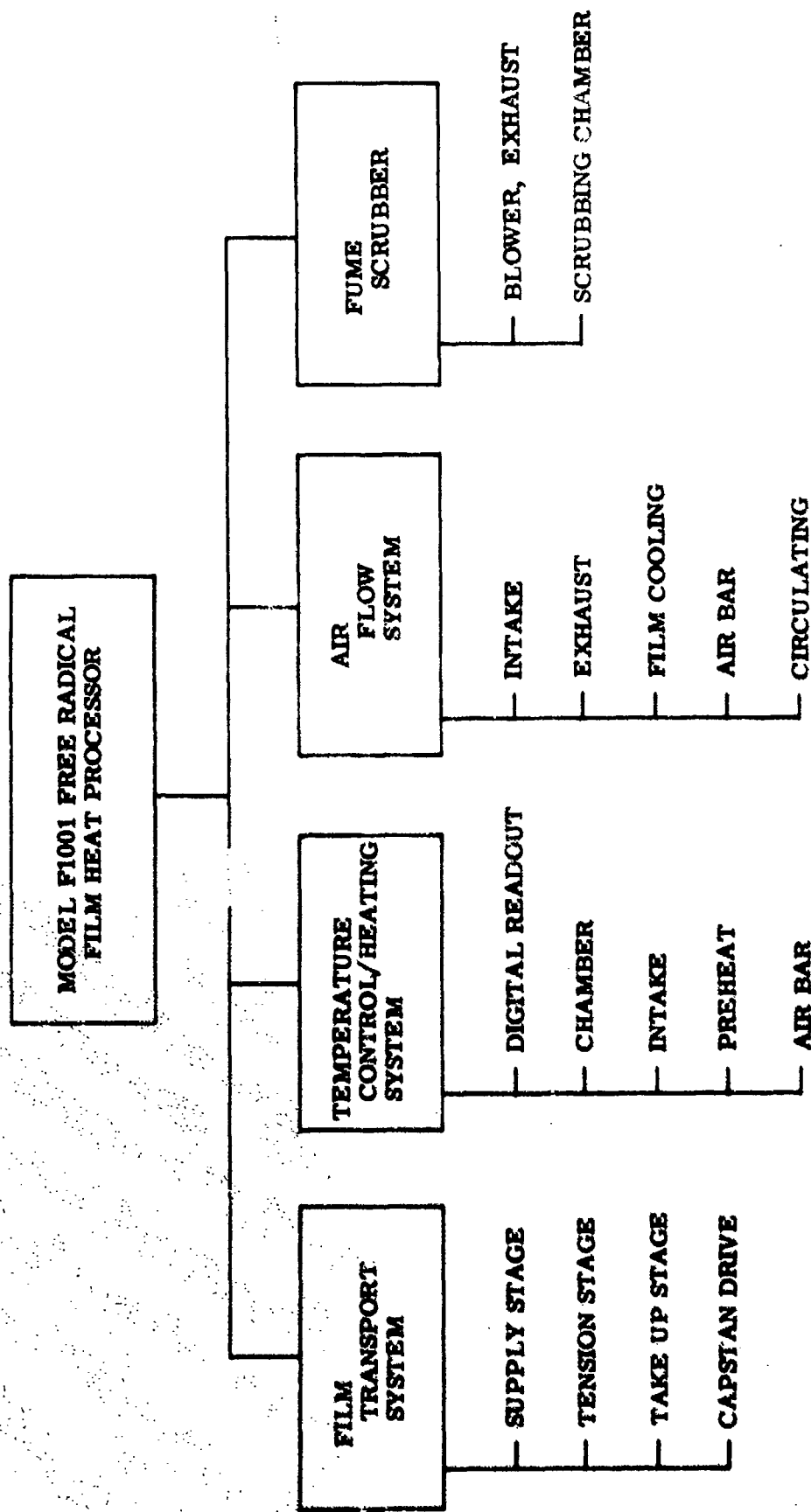
#### 3.1 GENERAL DESCRIPTION

The Model F1001 Free Radical Film Heat Processor was developed to process Photo Horizon, Inc., Free-Radical duplication roll film by the application of heat. The system consists of two units: a Processing unit and a Fume Scrubber. Located within the Processor unit are the Film Transport System, Temperature Control/Heating System and the Air Flow System. The aqueous Scrubber Unit includes two blowers, one to exhaust air from the Processor, and the other to exhaust air through the scrubber elements. Refer to Figure 1 for a block diagram of the Heat Processor. See Figure 2 for a photographic reproduction of the developed hardware. Inter-relationships of the various subsystems including the flow of air and film into and out of the Processor are shown in System Flow Diagram Figure 3.

The Free Radical Film Heat Processor is intended to provide one man with the equipment necessary to perform various processing tests over a wide range of film speed, film temperature and tension conditions. The development of the man-machine inter-relationships reflected a philosophy of orienting the input and output film stages and the major controls such that these three areas of primary concern can be visually monitored by the operator from one vantage point. Controls (see Figure 4) were grouped such that all similar functions were contained within well defined and outlined areas. Visual and audio indicators were utilized to alert the operator to proper function, malfunction or pending conditions.

A high degree of accuracy was desired in the temperature control units while keeping the operator's task as simple as possible. To obtain maximum precision, an illuminated digital temperature readout in conjunction with deviation meters were provided. Easy and quick adjusting controls were utilized to further relieve the operator's task. Threading diagrams were strategically located throughout the unit.





BLOCK DIAGRAM

FIGURE 1. MODEL F1001 FREE RADICAL FILM HEAT PROCESSOR

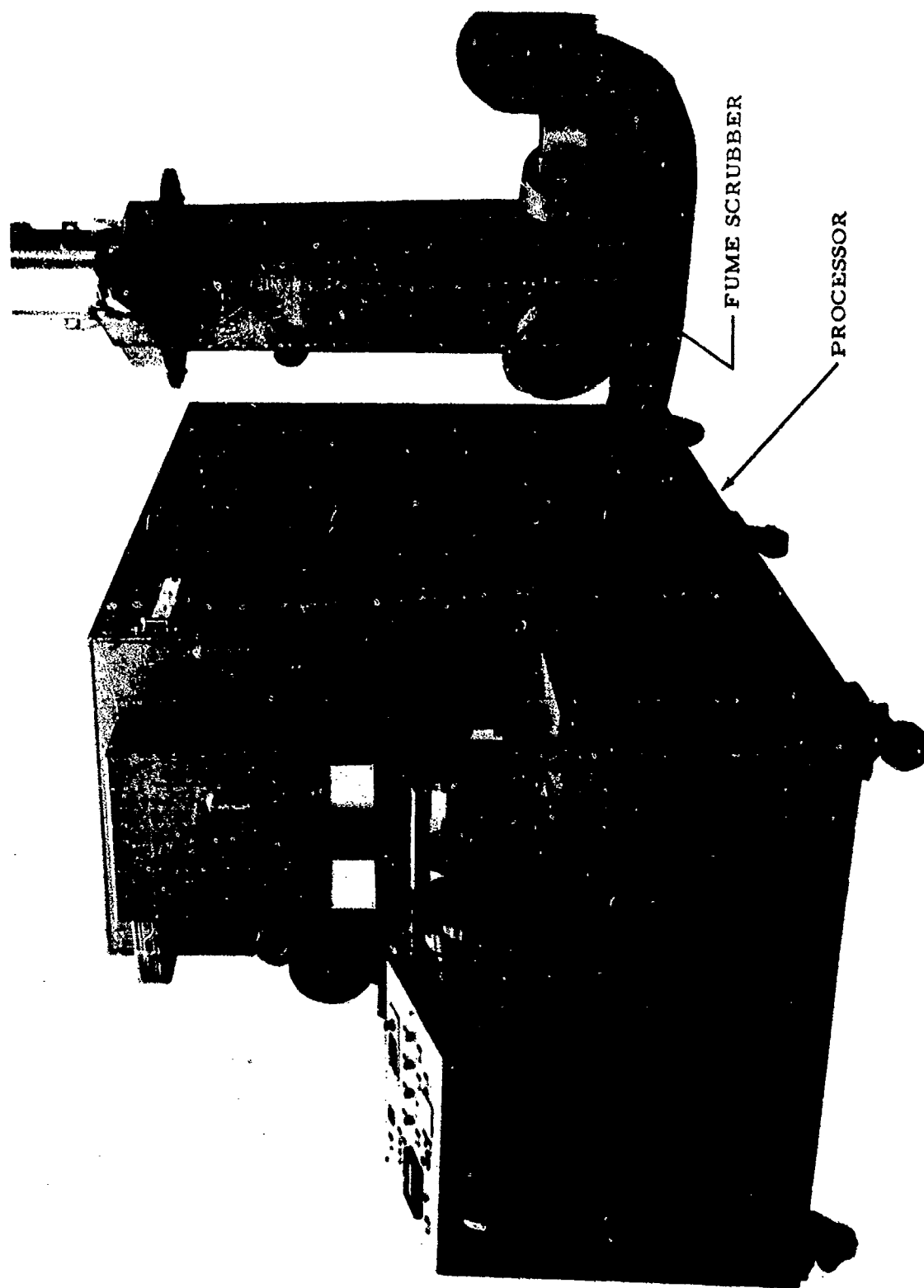


FIGURE 2. MODEL 1001 FREE RADICAL MATERIAL HEAT PROCESSOR

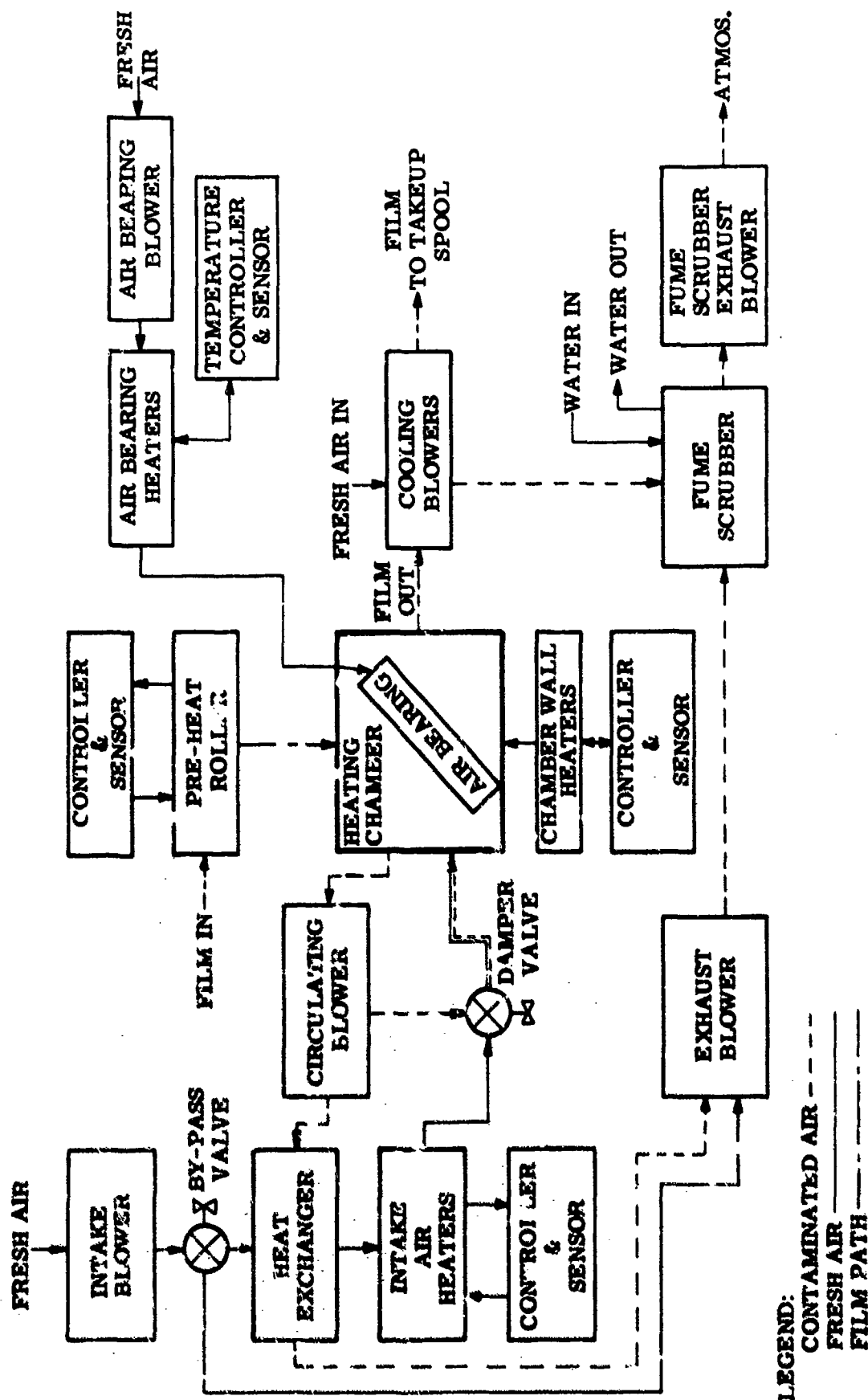


FIGURE 3. SYSTEM FLOW BLOCK DIAGRAM

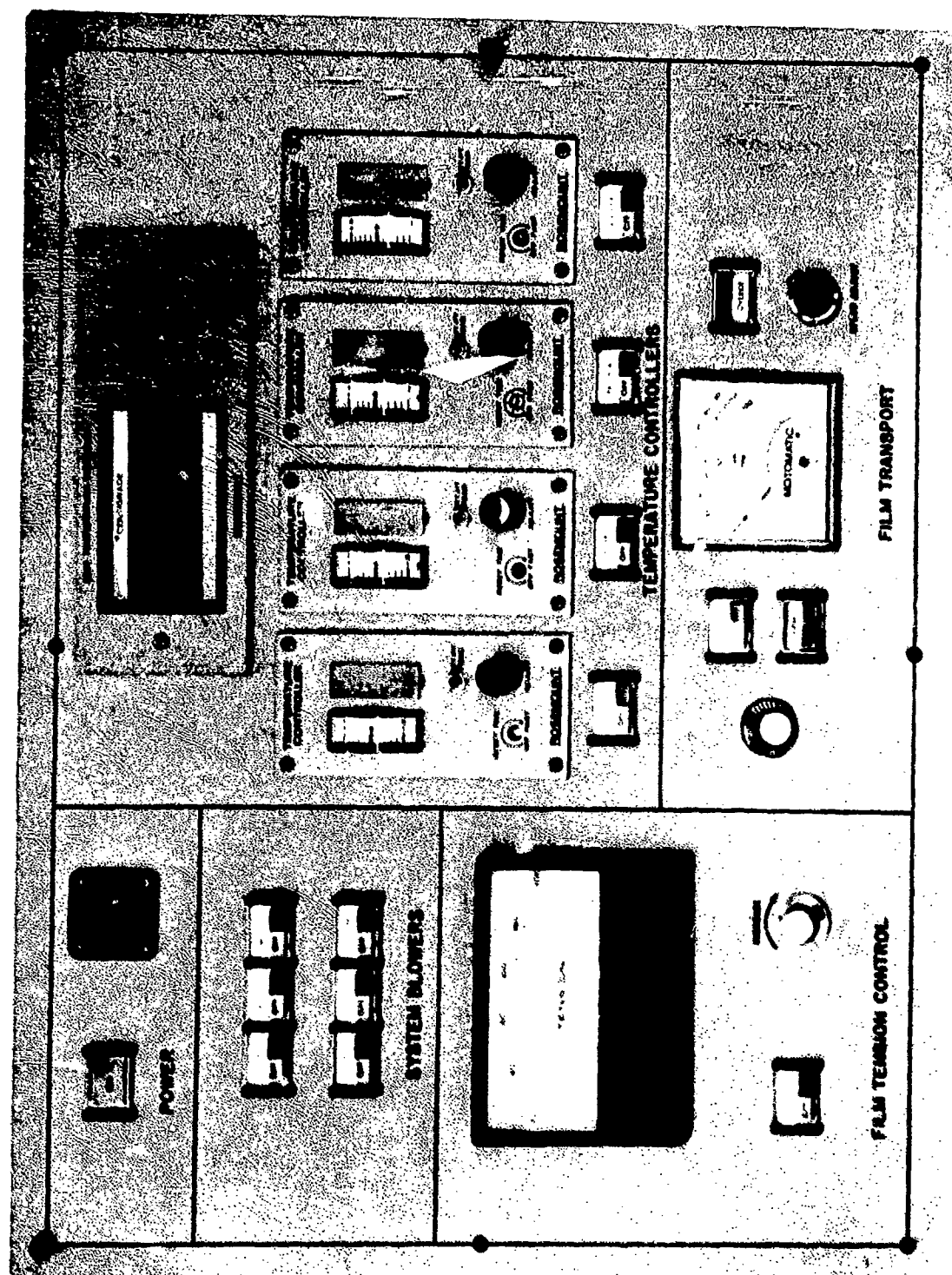


FIGURE 4. CONTROL PANEL

## SYSTEM SPECIFICATIONS.

<u>Unit Dimensions</u>	<u>Length</u>	<u>Width</u>	<u>Height</u>	<u>Weight</u>
Processor	120"	60"	72"	3,800 lbs.
Scrubber	60"	28"	110"	600 lbs.
<u>Film Transport</u>				
Transport Speed	5 - 100 fpm			
Tension Control	0.25 - 1.25 lbs/inch film width limited to 5 -25 fpm processing speed.			
Film Width	70mm - 9.5 inches			
Spool accommodation	MS26565 up to 10.5 inches dia.			
Film Length in Process Chamber	75 feet			
Film Material	Thermal Processed			
Film Base	0.003 to 0.0055 inch thick			
<u>Temperature Control</u>				
Range	100° - 170°C			
Display Resolution	0.1°C			
Control Accuracy	± 0.1°C			
<u>Air Requirements</u>				
Intake Air	1,000 cfm			
Film Cooling Air	200 cfm			
Exhaust Air (through Scrubber)	1,200 cfm			
Equipment Cooling	500 cfm			

### Fume Scrubber Requirements

Inlet Water	9 gallons per minute
Outlet Water	gravity drain

### Electrical Requirements

208 Volts, 3 Phase, 60Hz, 225 Ampere per Phase

### Operating Environment Limits

#### Laboratory Conditions

- Operating Temperature Range 50° - 100°F
- Relative Humidity 20% - 90%
- Storage Temperature 0° - 120°F

## SECTION IV

### FILM TRANSPORT SYSTEM

The Film Transport System consists of three separate sections: the film supply and tension sensing stage, a capstan drive, and a takeup spool drive. Constant film velocity is maintained by a servo driven capstan drive roller, film tension can be pre-set and controlled by tension sensing load cells, and a separate drive motor provides the necessary torque to wind film on the takeup spool. Film widths from 70 millimeters to 9.5 inches, base thickness ranging from 3.0 to 5.5 mils and MS26565 spools up to 10.5 inches diameter are accommodated. The system block diagram is shown in Figure 5.

#### 4.1 FILM PATH

Of primary concern in the design of the film transport system was the requirement to move film into and out of the heat processing area without contact between the emulsion side of the film and the machine when either is above 50°C. A heated film path length of 75 feet was required to achieve a 3 minute process time at a film transport rate of 25 feet per minute. This latter requirement mandated that the heated film path be at least 75 feet within the process chamber. Numerous film winding configurations were investigated with the final design being a resultant of numerous trade-offs between equipment performance, requirements of human factors, ease of loading/unloading, accessibility to operator, and economy of space.

To accommodate the 75 foot processing path length, the film is wound in a rectangular spiral fashion over a supporting frame which is designed with film support rollers at each corner of a particular wrap. Refer to Figure 6 for a pictorial representation of the film handling path. This design presented the most economical, compact film length within the heating chamber while satisfying the heat dwell-processing speed requirements.

A pre-heating roller pre-conditions the film prior to entry into the main heating chamber. Film direction is changed by 90° within the chamber by passing the web over a skewed 45° air-bar. It is then wound on the spiral film support assembly which is the main processing path through the heating chamber. The processed film then exits from the chamber, proceeds over the capstan drive unto the takeup spool. Total film path length from supply to takeup stage was approximately 90 feet.

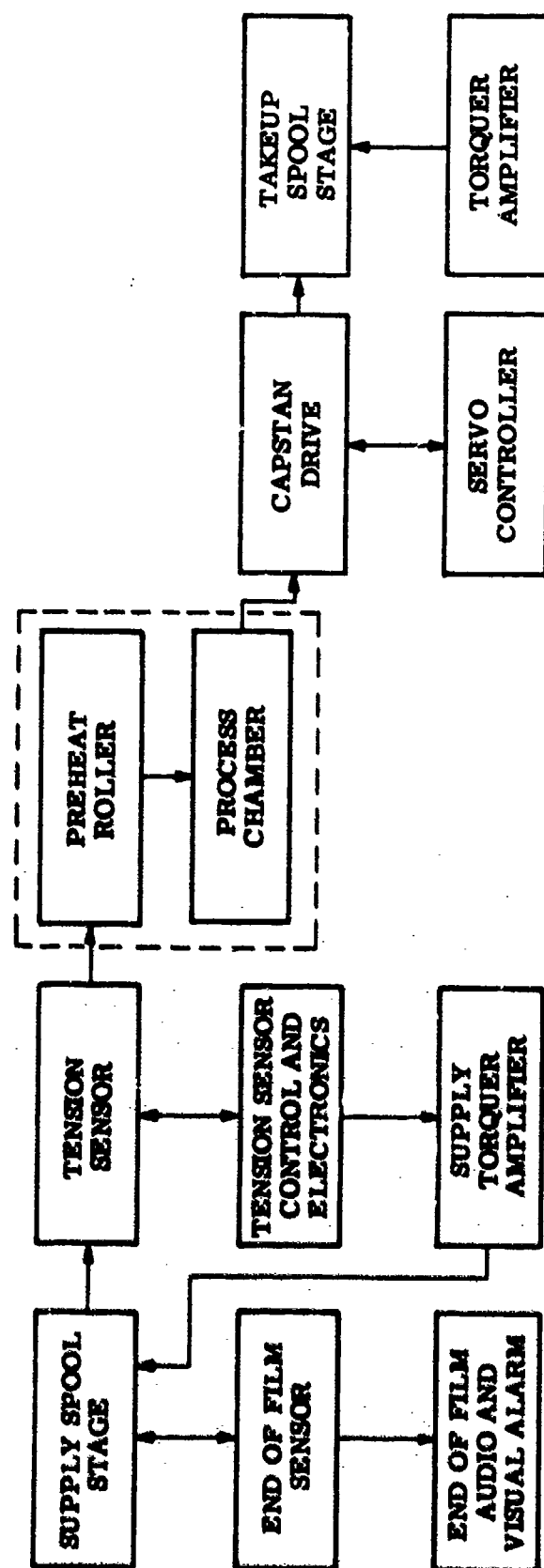


FIGURE 5. FILM TRANSPORT SYSTEM BLOCK DIAGRAM



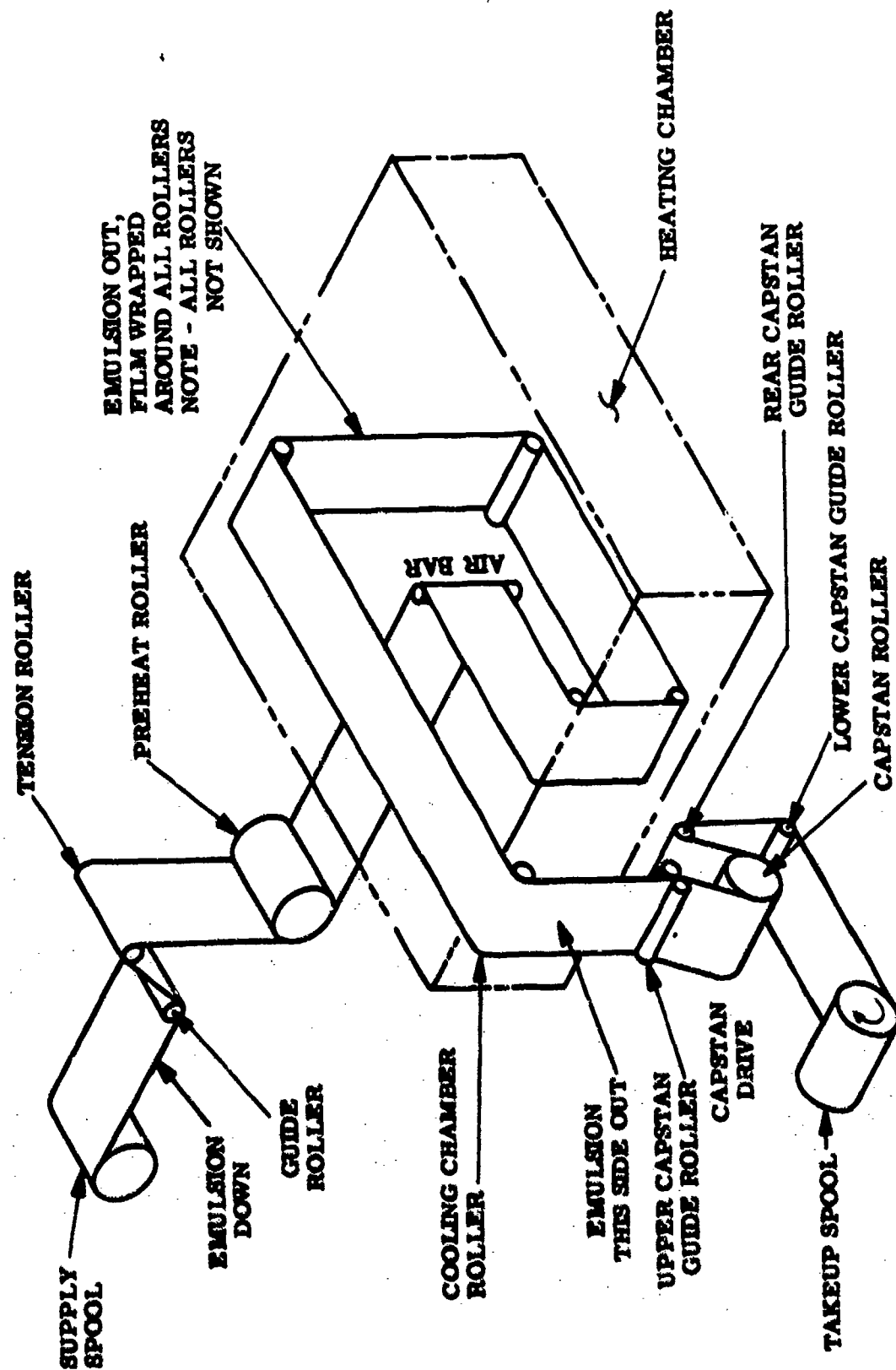


FIGURE 6. FILM THREADING DIAGRAM

Accurate film tracking was achieved by precise machining of all roller supports in order to maintain parallelism and orthogonality between the various members. All film transport components were dowel pinned to structural members to assure permanence of position.

The technique utilized resulted in a unique method for transporting film within the processing chamber without letting the emulsion side of the film come in contact with any rollers or the air-bar while either is above 50°C.

#### 4.2 CAPSTAN DRIVE

A capstan drive system was chosen to be the prime mover to drive the film at a precise linear velocity. The capstan roller diameter was sized so that its circumference was exactly 12 inches. An Electro-Craft, E650 DC servo motor drives the capstan roller through a 30:1 reduction gear box. Electrically, the servo motor is driven in a conventional closed loop velocity servo configuration using a manually generated command voltage and a velocity feedback signal from a tachometer integral with the motor. Selection of this drive motor was based on its one percent velocity stability characteristic over the required 0 to 5 inch pound torque range.

The capstan drive motor and controller consists of two basic units: a permanent magnet DC motor-generator and a solid state servo amplifier. The motor generator has two windings on the same armature, one for driving the motor and the other for generating a voltage proportional to speed. A signal from the generator is fed to the amplifier where it is compared to a reference voltage. A balance is maintained between the reference voltage and the generated voltage by the servo amplifier resulting in a closely maintained set speed regardless of changes in load or line voltage. Film velocity tests indicated that this system did indeed maintain constant film velocity to within  $\pm 1\%$  of set point regardless of tension applied to the film. Film speed can be varied from 5 to 100 feet per minute thereby permitting wide process time latitude (15 minutes to 0.8 minute).

Capstan drive motor selections were based on calculating the maximum torque required by the film drive system. Total required output torque is the sum of the force required to turn the Pre-heat Roller, the Support Roller Frame and the maximum tensile force on the film. Using a torque meter, it was found that the breaking torque to overcome static friction within the Pre-heat Roller was 5 in-lbs, and the breaking torque to drive the Support Roller Frame was 7 in-lbs. Torque required to pull film was calculated from:

$$T_c = F \times \frac{D}{2} = 11.875 \times \frac{3.822}{2} = 22.9 \text{ in-lbs}$$

where:

$T_c$  = torque required at capstan

$F$  = maximum tension on film in pounds (9.5 in. x  
1.25 lbs/in.)

$D$  = capstan diameter (inches)

Total required torque:

$$T_t = T_c + T_r + T_p$$

$$= 22.9 + 7 + 5$$

$$T_t = 34.9 \text{ in-lbs}$$

Motor torque:

$$T_m = \frac{T_t}{G_R \times e}$$

$$T_m = \frac{34.9}{30 \times 0.9} = 1.3 \text{ in-lbs.}$$

where:

$T_t$  = total torque

$T_r$  = Roller Frame torque

$T_p$  = Pre-heat Roller torque

$T_m$  = drive motor torque

$G_r$  = gear box reduction

$e$  = efficiency of gear box

Output torque of the E650 is a constant 5 in-lbs over a speed range of from 3 to 3,000 revolutions per minute which, when geared down to a 30:1 ratio, is compatible with the 5 to 100 feet per minute film velocity requirement.

Servo motor regulation contours and system performance curves indicated that the chosen E650 servo motor will operate well within the 1% accuracy requirement of the specification. Actual tests verified that throughout the tension speed range (0.25 to 1.25 pounds per inch of film width and 5 to 25 feet per minute) drive accuracy was repeatable to better than the  $\pm 1\%$  requirement. High speed transport tests (100 feet per minute) also confirmed that the capstan drive unit was accurate and repeatable to better than the 1% specification criteria.

#### 4.3 TENSION-SUPPLY STAGE

A tension sensing roller and a DC torquer motor are utilized to sense and maintain constant film tension. Measurement of the actual tension in the film is made by sensing, with strain gage transducers, the force on a guide roller caused by web tension. The electrical signal from the transducers is amplified by a solid state amplifier and displayed on a tension indicator meter. The use of two transducers rather than a single one eliminates any errors or inaccuracies in tension measurement that result when the web is not centered, or is alternately slack and tight on one edge.

The guide roller utilized as the tension sensing roll is an idle (non-driven) free turning member. Another free roller is utilized in the tension control system to provide means of a constant wrap angle regardless of supply spool diameter.

A signal proportional to tension is derived from the tension transducer amplifier and is introduced into a power servo amplifier to control output torque of an Inland Corporation DC torque motor located at the supply spool support spindle. The applied control voltage causes the torquer motor to rotate in the opposite direction of film travel thus acting as a dynamic brake. This design permitted adjusting and maintaining constant tension on a film roll over a range of from 0.25 to 1.25 pounds per inch of film with a one percent accuracy.

The use of a fixed position tension sensing roller simplified tracking alignments and did not present problems normally encountered when utilizing more conventional means of sensing tension such as that incurred with "dancing rollers" and spool diameter sensing arms.

The tension control motor selection was based on torque requirements and minimum-maximum spool speeds. Since the film transport system was to accommodate all MS26565 type photographic spools, it was necessary to compute maximum extremes of angular speed of the various spools. Calculation showed that for a film linear velocity of 5 to 100 feet per minute the motor would have to accommodate angular velocities of from 1.8 to 395 revolutions per minute. Further analysis indicated that when we consider the use of the

smallest width (70 millimeter) spools to the largest width (9.5 inch film) spools, the tension motor would require the capability of providing torque from 0.03 to 5.2 foot-pounds. A search for a motor having the above dynamic capability resulted in the selection of an Inland torque motor T-5730. Tests demonstrated this motor to be capable of providing proper tension on the film throughout the required range.

#### 4.4

#### FILM SUPPORT ASSEMBLY

A Film Support Roller Assembly is used to support the film within the processing chamber. This frame contains film support rollers, drive sprockets, and chain as shown in Figure 7. All rollers are thin walled aluminum tubes with an Alodine 1200 chemical coating and mounted on a set of stainless steel ball bearings. The bearings are in turn mounted on a driven sprocket shaft assembly which is connected to and driven at the same linear velocity as the capstan drive. The roller design is illustrated in Figure 8. During operation, the sprocket shaft assembly rotates, overcoming frictional forces of the conventionally mounted bearings and driving the low inertia rollers. The rotating force is transmitted to the roller through the ball bearing friction and the lubricant viscosity. Since the rollers are all power driven at a speed corresponding to capstan speed, the film does not have to provide the driving torque for the large number (33) of rollers. This design, however, permits minor speed variations between rollers to allow for minute variations in roller and capstan diameters and for film shrinkage. Constant tension was accomplished within the film support assembly with this design.

#### 4.5

#### FILM TAKE-UP STAGE

A DC torque motor located at the film take-up stage provides the necessary torque to wind film on the take-up spool and also provides means for tight film wrap on the capstan roller. The necessary power for proper winding is provided by a constant current generator. A potentiometer control allows motor torque to be adjusted to the needs of the various film widths and tensions. In operation, the current applied to the take-up torquer is defined in a chart which permits the operator to adjust the potentiometers to correspond to a particular tension setting. The take-up motor windup torque is sufficient to permit tight film wrap on the capstan roller without causing slippage. Film tension during processing is not influenced by the take-up torquer motor since the capstan isolates the take-up torque from the rest of the transport system.

Motor sizing was accomplished by first determining maximum tension that must be applied to the film on the output side of the capstan in order to prevent slippage between capstan roller and film, and secondly by calculating required motor torque considering "worst" case MS26565 spool conditions. From the belt friction equation, neglecting centrifugal force:

$$T_1 = T_2 e^{f\alpha}$$

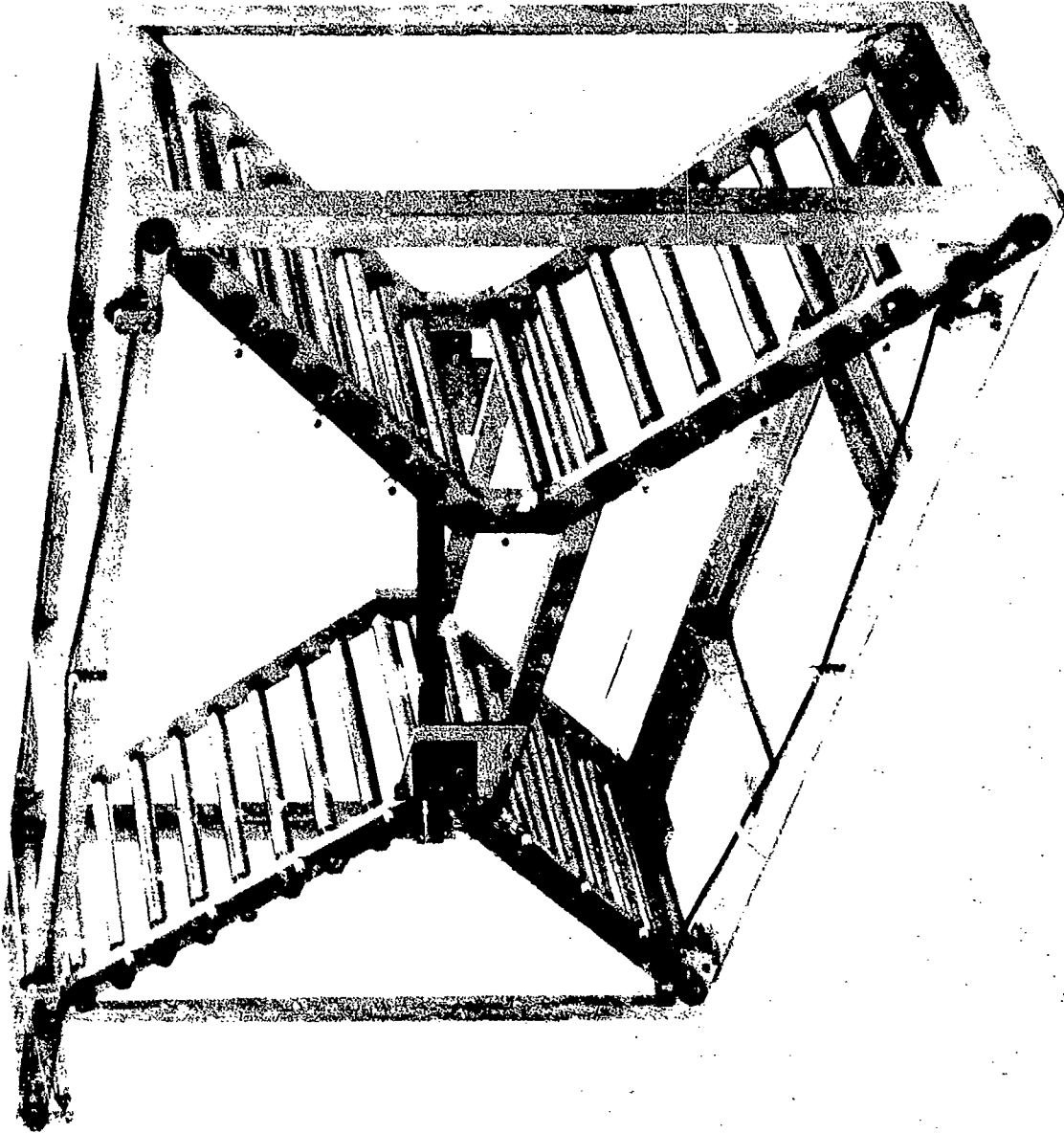


FIGURE 7. FILM SUPPORT ROLLER ASSEMBLY

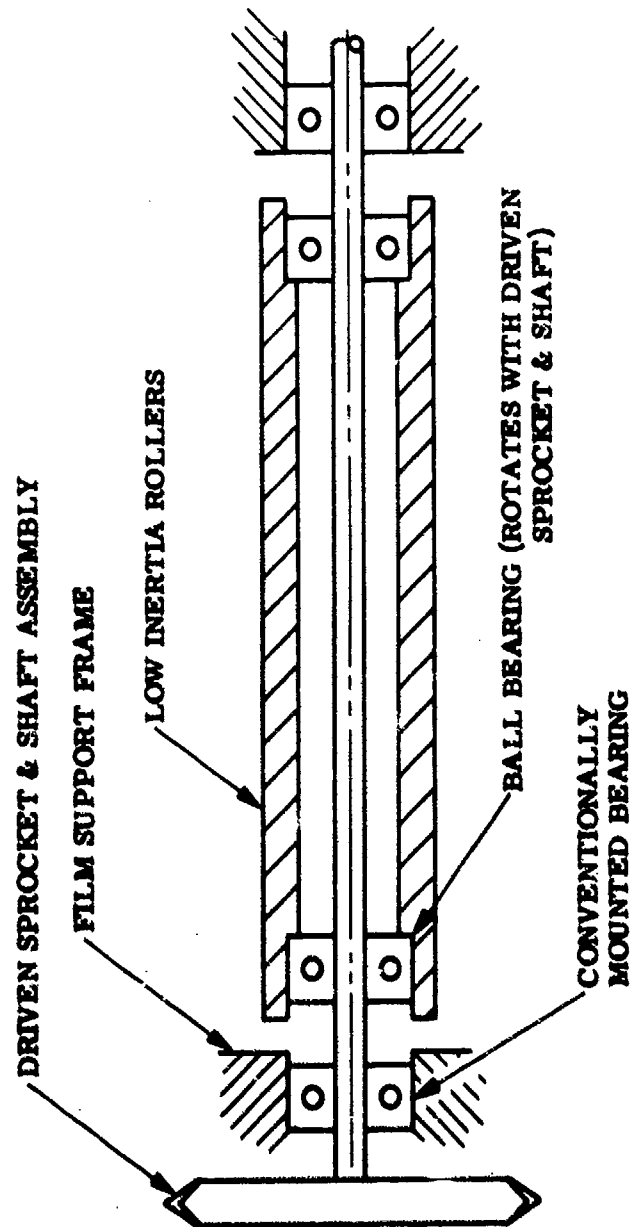


FIGURE 8. ROLLER DESIGN

where:

$T_1$  = tension applied to film by capstan (max) = 11.875 lbs

$T_2$  = tension required by takeup motor

$e$  = 2.7183

$\alpha$  = angle of wrap = 4.2 Radians

$f$  = coefficient of friction (polyester on aluminum alloy = 0.45)

Substituting and rearranging terms:

$T_2$  = 1.83 lbs.

Determining maximum torque required for continuous tension during takeup:

$$T_m = T_s \cdot \frac{D_s}{2} \cdot F_s$$

$$T_m = 1.83 \times \frac{10.5}{2} \times 1.5 = 14.4 \text{ in-lbs}$$

where:

$T_m$  = takeup motor torque

$D_s$  = worst case spool diameter (10.5 inches)

$F_s$  = service factor

An Inland T-4036 torquer motor having a 28 in-lb capacity was utilized in the design. Although this motor had a greater capability than needed, its production status and off-the-shelf availability justified its use.

#### 4.6 END OF FILM SENSOR

An end-of-film sensor is provided at the supply stage to alert the operator to film roll depletion. This sensor is a lightly spring loaded arm contacting one edge of the supply film roll which actuates a light on the control panel and an audio alarm when it reaches a preset diameter. This feature was essential to the design when one considers the extremely long film path length and the



time required to cool the processing chamber to a safe level before re-threading can be accomplished by the operator. A 75 foot trailer is needed to allow the test film to completely exit the heat chamber after completion of processing.

## SECTION V

### TEMPERATURE CONTROL SYSTEM

Performance requirements for the Processor heating chamber necessitated that the temperature control system be operator selectable over a range of from 100° to 170° Centigrade (°C) and that it maintain the preset temperature to within  $\pm 1^\circ\text{C}$ . In addition, self controlling features were required to maintain the selected parameters throughout continuous operating periods of six hours. A series of heaters, power pods, temperature sensors and controllers were utilized to achieve the desired results. The system controlled and monitored chamber wall, pre-heat roller, air bar and intake air heaters.

Four Rosemounts, Inc. time proportionical controllers were utilized in the system with a multi-channel digital temperature indicator to display setpoint and sensor temperature of each controller. In addition, a calibrated sensor was utilized to display heating chamber temperature. Each controller had a specific function and the capability of independent adjustment to balance system losses. The inter-relationship between the controllers and display is shown in Figure 9.

#### 5.1 CONTROLLERS

The basic 3010 series controllers manufactured by Rosemount Inc. consisted of a measuring bridge employing a platinum resistance bulb as a temperature sensor, a pre-amplifier, an output circuit card, a meter circuit and a power supply.

The electrical resistance of the platinum sensor bulb, located at the point where the controlled temperature is maintained, changes in direct linear proportion to the sensor's temperature.

The combination of temperature sensor, temperature controller, final control element and heat source together control temperature using closed loop proportional control. When power is initially switched on to the control system and the controller set point is adjusted to a desired temperature, the resistance of the temperature sensor will be less than that of the set point adjustment because the load temperature is less than set point temperature. With these conditions, the measuring bridge will have a positive output voltage. The preamplifier will amplify this voltage which will cause the controller output voltage to increase. This, in turn, increases power pack output applied to the heating element raising the temperature of the load and thus the temperature of the resistance sensor. When the resistance sensor temperature reaches set point temperature setting,

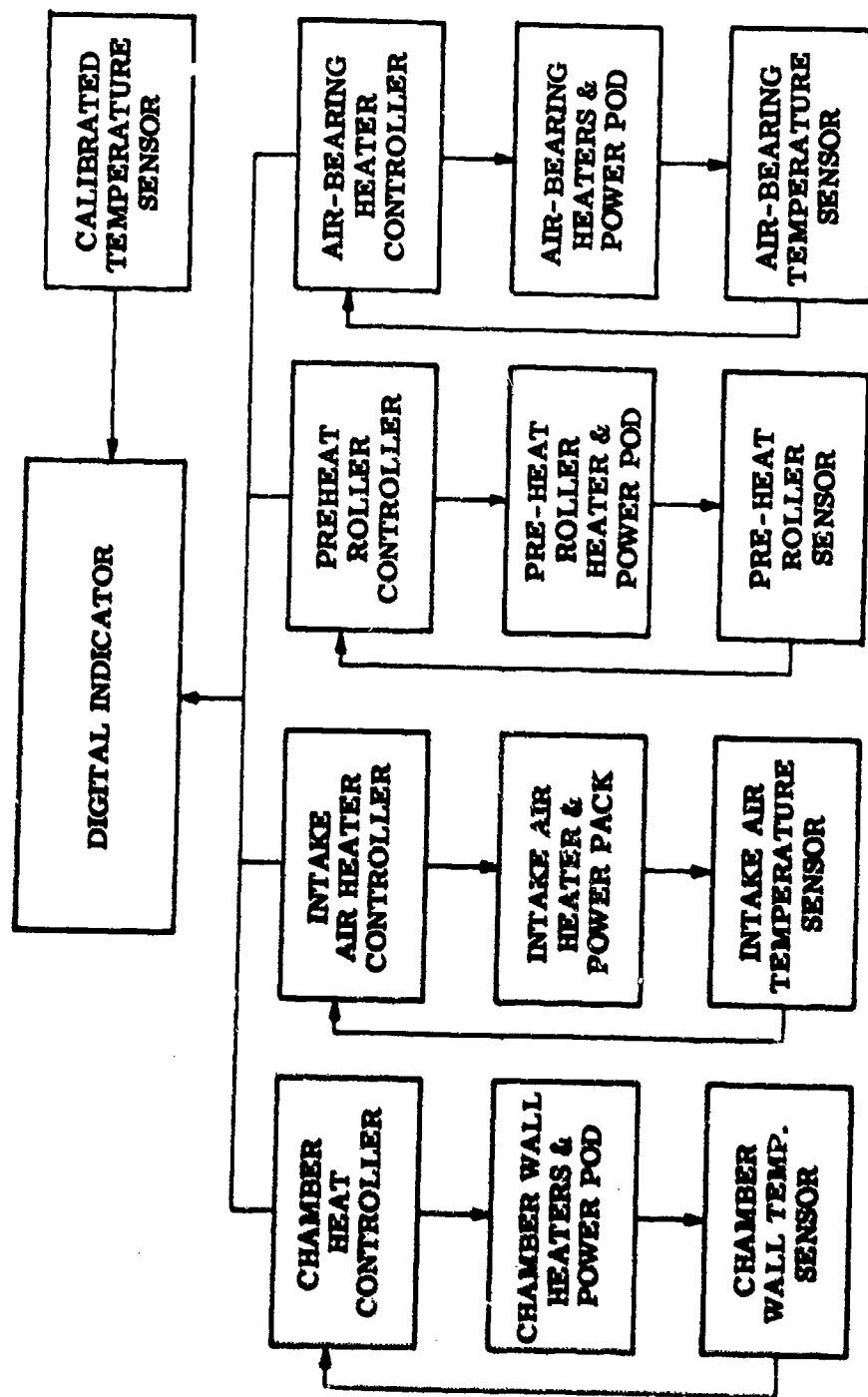


FIGURE 9. TEMPERATURE CONTROL SYSTEM BLOCK DIAGRAM

the temperature sensor resistance will equal the resistance of the setpoint adjustment and the bridge output will drop to zero. This causes the controller output to become zero and, therefore, the power applied to the heating element will become zero.

Three of the four controllers provide control signals to the power pods (Rosemount Model 3042) which allow power to be applied to the chamber wall heaters, pre-heat roller and the air-bar heaters. These pods utilize single phase power and are solid state triac power controls. The fourth controller is a modified (Model 3019) controller which controls a Robicon Corporation, three phase SCR power pack, which fires the two 22.2 kilowatt main heaters, for the control of intake processing air temperature.

All four controllers are wired into a Rosemount, Model 2509, digital temperature indicator for display of setpoint and sensor temperatures. A selector switch permits operator selection of any one of five channels. The first channel is merely a display, indicating the process chamber temperature. Selection of any of the remaining four channels reflect any one of four controllers. Displayed temperature is in degrees centigrade with resolution of 0.1°C.

Maximum system accuracy was achieved by calibrating the channel one sensor and adjusting the digital temperature indicator such that its response was linear to the sensor resistance over a range of from 100°C to 170°C. This linearization resulted in the channel one display to have an accuracy of  $\pm 0.1^\circ\text{C}$ . The remaining four channels were also linearized over the processing range of 100°C to 170°C and are accurate in display and control to within 0.25°C. Thus, the temperature controllers and display device were specially adjusted and tuned as a system in order to control process chamber temperature to the required tolerance of  $\pm 1^\circ\text{C}$ . Controller, power pods, and sensor working in conjunction with each other are:

<u>Controller</u> <u>Rosemount Model</u>	<u>Power Pod</u>	<u>Sensor Model</u>	<u>Control/Monitor</u>
3019	3042	108MA2AX	Chamber Wall
3019	3042	0106-80001	Pre-heat Roller
3019	3042	104MB8BACBX	Air-bar
3019	3049	104MN200C	Intake Air

In addition, the digital temperature display Model 2509 was used with sensor model 104MC100C to monitor process chamber temperature.

## 5.2

## SYSTEM HEATERS

A series of four resistance type heaters were utilized in the unit to maintain the processing chamber temperature within the required temperature range and tolerance. These heaters were used to heat the intake air, overcome chamber wall temperature leakage, pre-heat the film prior to entry into the process chamber and heat the air for the air-bar.

## 5.2.1

## Intake Air Heaters

Heater capacity for the 1,000 cubic feet per minute of processing air was determined by analyzing "worst" case operating conditions. Largest heaters are needed when the unit would be required to operate under the following anticipated extreme ambient conditions:

- Temperature	50°F
- Relative Humidity	90%
- Highest Temperature	338°F (170°C)
- Air Flow	100%

Initial calculations were performed to determine power required to heat the air under the above worst case steady flow conditions:

$$\text{Relative Humidity} = \frac{\text{Pressure of Water}}{\text{Saturation Pressure}}$$

$$0.9 = \frac{P_{H_2O}}{.1781}$$

$$P_{H_2O} = .16029 \text{ lbs/in}^2 \quad \therefore P_{air} = 14.7 - .16 = 14.54 \text{ lb/in}^2$$

Specific wgt ( ) of air at 50°F:

$$\rho_{air} = .07702 \text{ lbs/ft}^3$$

$$\rho_{H_2O} = .00053 \text{ lbs/ft}^3$$

$$\rho_{mix} = .0775 \text{ lbs/ft}^3$$

For the mixture at 338°F:

$$\rho_{\text{air}} = .0492 \text{ lbs/ft}^3$$

$$\rho_{\text{H}_2\text{O}} = .00034 \text{ lbs/ft}^3$$

$$\rho_{\text{mix}} = .0495 \text{ lbs/ft}^3$$

Flow of air mixture ( $\dot{V}$ ) in processor (with 50 feet per minute air flow across film) is:

$$\dot{V} = A_f V = 56,220 \text{ ft}^3/\text{hr.}$$

where  $A_f$  = Process Chamber Flow Area

The weight rate ( $\dot{W}$ ) of air flow in the processor is:

$$\dot{W} = \rho_{\text{mix}} \dot{V} = 2782.9 \text{ lbs/hr}$$

The weight of the supply components:

$$\dot{W}_{\text{air}} = \dot{W}_{\text{supply}} \left( \frac{\rho_{\text{air}}}{\rho_{\text{mix}}} \right)_{338}$$

$$\dot{W}_{\text{H}_2\text{O}} = \dot{W}_{\text{supply}} \left( \frac{\rho_{\text{H}_2\text{O}}}{\rho_{\text{mix}}} \right)_{338}$$

determine heat flow ( $\dot{q}$ ):

$$\dot{q} = (\dot{W} C_p \Delta t)_{\text{air}} + \dot{W} \Delta h_{\text{H}_2\text{O}} = 211,947 \text{ BTU/hr}$$

$$= 62,100 \text{ watts}$$

where:

$\Delta t$  = change in temperature

$C_p$  = specific heat assuming constant pressure

$h$  = enthalpy for the water vapor in the mixture

To reduce the total energy required to heat the air, a heat exchanger was designed into the air duct system. This unit was designed to be installed at the outlet end of the process chamber and was arranged for two passes of hot air to flow through in a cross counterflow manner. Ambient temperature air is forced through a number (264) of 0.375 inch diameter copper tubes by the intake blower. Aluminum fins attached to the outside of the tubes transfers the heat from the hot exhaust air to the tubes which in turn heats the incoming cool air. A heat transfer analysis on system design constraints indicated that it would be possible to recover an energy rate of 27,000 watts based on 1,000 CFM of air heated to 338°F flowing through the system. Computations showed that the air temperature on the discharge side to be 212°F. Temperature tests conducted after assembly verified that the heat exchanger was more efficient than the analysis indicated since the outlet air temperature was measured to be 170°F.

The use of the heater exchanger, therefore, resulted in a power savings of approximately 43% which reduced main heater requirements from the initial 62.1KW to 35.1KW.

Proper design in the selection of the heaters necessitated that the heater surface be as large as possible and also provide the maximum amount of turbulence in order to obtain thorough, uniform mixing, and heating of the air. Two Trent Inc. heaters having 22,200 watt capacity each were selected. These heaters have folded and formed heating elements and are of the exposed ribbon type having greater cross section area than conventional coiled wire open elements. A unique forming operation gives the self supporting elements a structural rigidity that prevents sag when operated at high temperatures. These units because of their lower mass (than the metal sheathed heater) respond faster to heating and cooling. The greater surface area (low watt density) dissipates heat at a faster rate, thus operating at lower temperatures and prolonging element life.

Utilization of two heaters, mechanically installed in series with each other, provided large surface element areas while allowing maximum air-heater contact time. Oven temperature reset controls and air flow safety switches were included in the air duct to provide heater-blower interlock conditions thereby safeguarding the heater cores in the event of air blockage or blower malfunction.

A major feature of the air heating design was that no contaminated processing air was allowed to pass over a heating element in order to prevent destructive decomposition of the effluent gases and corrosion of the heating elements.

### 5.2.2

#### Chamber Wall Heaters

The interior walls of the heat processor chamber were lined with blanket heaters to offset thermal leakage through the walls and also to provide a degree of fine temperature control within the chamber. Thermal calculations indicated that the wall losses amounted to approximately 6,500 BTU per hour. Consequently blanket heaters having 2,200 watt (7,500 BTU/hr) capacity were installed. These heaters were constructed of Nichrome wire evenly spaced and embedded in a thin layer of silicone rubber and cemented to an aluminum backing board so as to provide very uniform heat distribution across the entire surface area. The panels were fastened to the chamber walls with the aluminum facing the chamber interior.

Electrically the panels were joined in a parallel circuit and controlled by a Rosemount temperature controller. A platinum resistance surface sensor was utilized to provide controller feedback.

### 5.2.3

#### Air-Bar Heaters

An initial design assumption indicated that air utilized for the air-bar would be drawn from the processing chamber and continuously circulated through the pump-air-bar-process chamber. This approach would eliminate the need for heaters, controllers, etc. However, upon searching for an air pump that could handle 338°F (170°C) air, it became apparent that the search was futile since developed hardware did not exist that would be conducive to the operating parameters. Vendor responses were all more or less typical in that a blower capable of being used within the operating parameters would have to be developed, would require long lead time (minimum one year), would necessitate water cooling of the bearings and would require exacting information as to gases being emitted from the film during processing. Since these responses did not fit the contract timetable and also that the resultant blower might turn out to be a risky performance venture, it was decided to purchase an off-the-shelf blower and heat the air prior to delivery to the air-bar.

Utilization of this design approach permitted a choice of blowers and a realizable delivery schedule; however, it was necessary to provide air heating elements and a temperature control system. A thermal analysis based on air flow requirements, needed to float the film around the air bar, indicated that a heater having a thermal capacity of 4,027 watts would be required. Since this air was to be continuously discharged into the processing chamber, it was mandatory that temperature control be exacting and that the air stream be of uniform temperature prior to entering into the processing chamber. Improper mixing or loose control would have a detrimental effect on process chamber uniformity.

The air flow design, therefore, allowed air, pumped by the Gast, Inc. blower (discussed in paragraph 6.5) to be forced through a heating tube which contained



three, 1,800 watt, coiled wire heaters, Model 821, manufactured by the Master Appliance Corp. Turbulence and proper mixing was achieved by the heater element design whose mechanical configuration caused the air stream to impinge on the heating elements over a heating length of approximately 18 inches. In addition, the 2 inch diameter heating tube was gradually tapered to a one inch transition tube, thereby causing further mixing and agitation of the stream. A platinum temperature sensor located down stream of the transition tube provided the necessary feedback signal to the Rosemount temperature controller. Test data taken during temperature trials indicated that over a 6 hour period processing air temperature was maintained within  $\pm 0.1^{\circ}\text{C}$  of the set point.

#### 5.2.4 Pre-Heat Roller

Non-processed film, prior to entry into the processing chamber, is preheated to minimize its thermal impact on chamber uniformity. This was accomplished by allowing the film to enter a pre-heating chamber containing a pre-heating roller. The film base contacts the roller, which through thermal conduction, raises the film temperature to any pre-selectable preheat temperature within the range of  $100^{\circ}\text{C}$  to  $170^{\circ}\text{C}$ .

Design of the pre-heat roller (see Figure 10) utilizes a fixed cartridge heater at the core of a rotating roller. Roller speed is proportional to film linear velocity and is driven by the film capstan drive. This design assures that the film does not have structural stresses implied on it by driving the roller.

Cartridge heater sizing was determined by standard heat transfer equations considering angle of roller contact by the film ( $90^{\circ}$ ), maximum film speed (25 feet per minute) and the thickest film anticipated (0.0055 inch). The analysis indicated the need for a 1,200 watt heater. A 2,200 watt heater was used to obtain full 9.5 inch film width coverage.

Roller temperature was sensed by a non-contacting, low mass, wire type, platinum resistance sensor located in a shoulder machined at the surface of the roller. A ring enclosed the machined shoulder such that the net result was an annular slot which contained the sensor. The slot was sized to provide minimum clearance between the sensor diameter and slot width thereby minimizing thermal lags. Control was accomplished by sensor feedback signal to the Rosemount temperature controller which in turn regulated input power to the cartridge heater.

The pre-heat roller was enclosed in an insulated chamber and located prior to the film entry slot of the processing chamber. Marinite, a fireproof structural insulating material, manufactured by the Johns-Manville Corporation, was used to line the chamber. The two inch thick Marinite was chosen for its structural integrity, lightweight and low thermal conductivity. A sheetmetal outer shell encompassed the insulating material to increase exterior surface durability and utility.

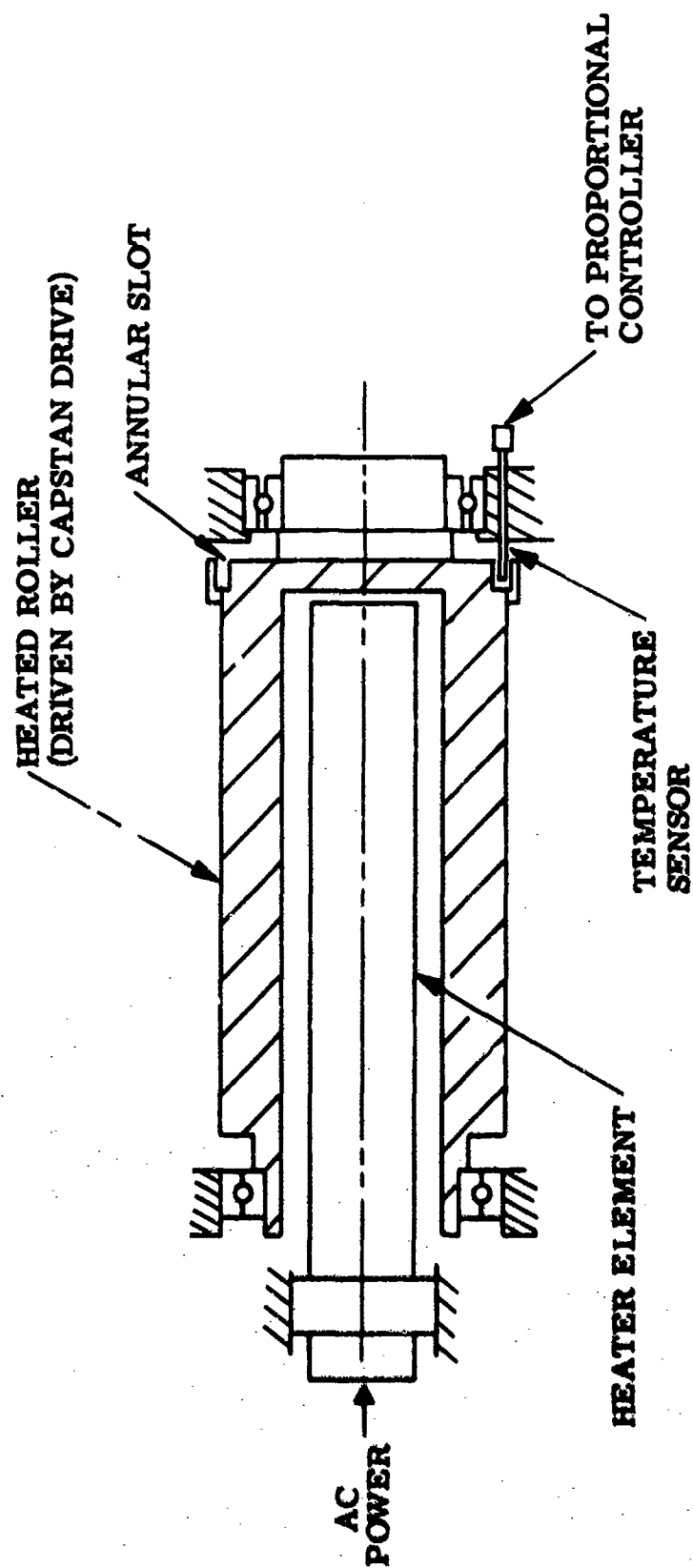


FIGURE 10. PRE-HEAT ROLLER SCHEMATIC

A prime operating feature of the Heat Processor was the need for the unit to display uniform temperatures within the processing chamber. Temperature specification requirements mandated that the Temperature Control system not only permit accurate control but also provide uniformity within the processing chamber to a  $\pm 1.0^\circ\text{C}$  tolerance for a six hour period. To verify that the system was indeed capable of performing to the specification, a test was established to monitor chamber temperature and uniformity for the required six hour period.

Twenty copper-constantan calibrated thermocouples were placed within the processing chamber. Distribution of the thermocouples resulted in full coverage of the film path within the chamber. A Honeywell Inc. multipoint recorder permitted periodic thermocouple printout. Temperature tests were conducted at both the high ( $170^\circ\text{C}$ ) and low ( $100^\circ\text{C}$ ) extremes of the temperature requirement. Data taken throughout a continuous six hours indicated that the unit exhibited a high degree of stability and repeatability. A statistical analysis indicated that the standard deviation ( $\sigma$ ) for the  $170^\circ\text{C}$  test was  $\sigma = \pm 0.83^\circ\text{C}$ , while  $\sigma = \pm 0.72^\circ\text{C}$  for the  $100^\circ\text{C}$  test. The data also indicated that during the  $170^\circ\text{C}$  test all test points remained stable with  $\pm 0.56^\circ\text{C}$ , while the test points remained within  $\pm 0.83^\circ\text{C}$  for the  $100^\circ\text{C}$  test. The majority of the test points in both cases remained within  $\pm 0.56^\circ\text{C}$ .

Test conclusions resulted in acceptance of the Temperature Control System.

## SECTION VI

### AIR FLOW SYSTEM

A system of blowers is incorporated into the design to provide means for forced convection heating of film and to exhaust contaminated air out of the processing chamber. In addition, small auxiliary blowers are used to cool the film upon exiting from the processor chamber. A system block diagram is shown in Figure 11. The intake blower pushes room ambient air past a heat exchanger, over a dual set of high temperature heaters and into the heating chamber where it is directed across the film path. An exhaust blower pulls the contaminated air out of the processing chamber through the heat exchanger and into the Fume Scrubber.

Two manually operated controls, a Damper and By-Pass valve, are provided to permit air refreshing rate of from 10 to 100 percent. A circulating blower within the process chamber is utilized to circulate the air during the re-circulatory mode.

#### 6.1 FLOW ANALYSIS

An air flow analysis was performed to determine the various pressure drops throughout the system in order that blower sizes could be selected.

##### Parametric Conditions

###### Inlet Air:

- Temperature 50°F min.
- Relative Humidity 90% max.
- Total flow in processor 100%
- Processor temperature 338°F (170°C)

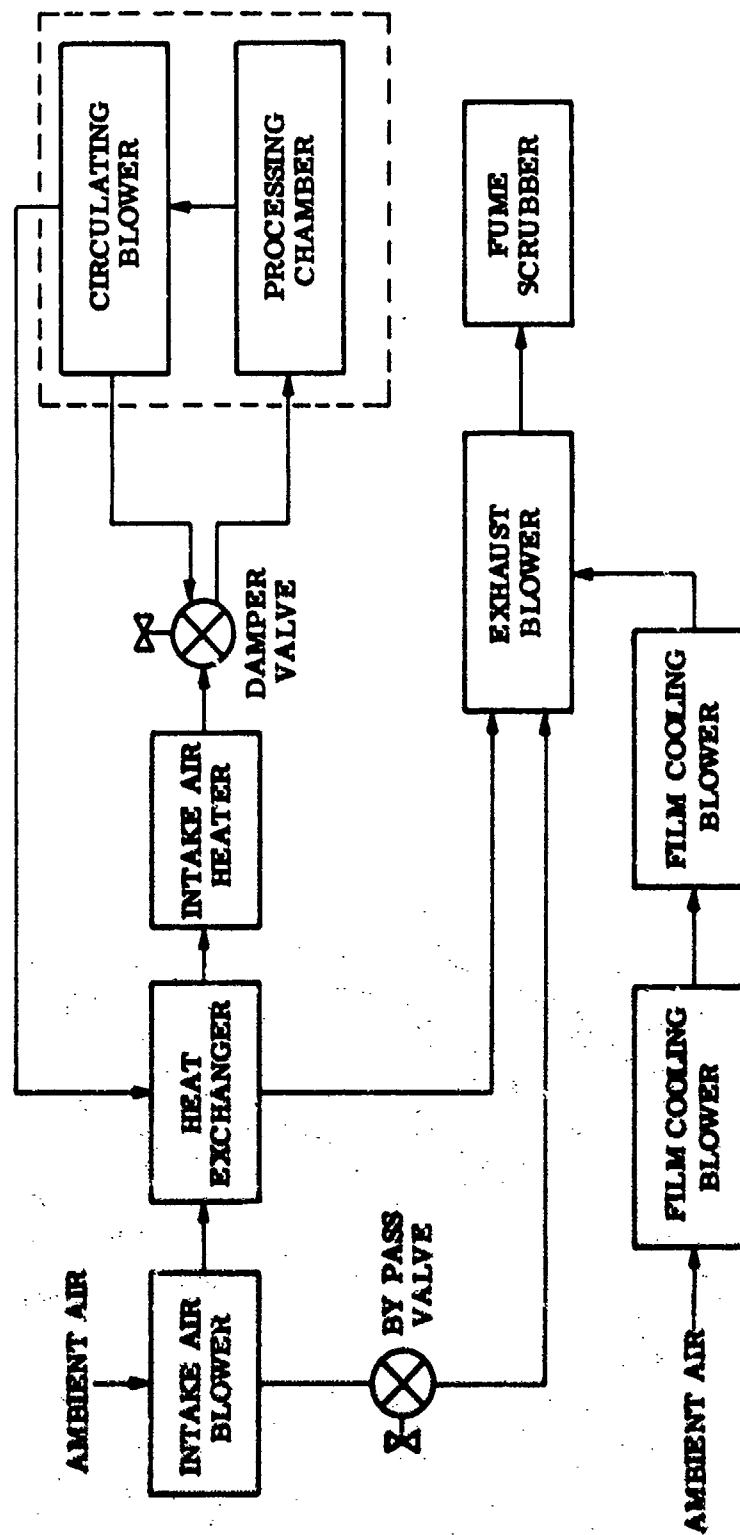


FIGURE 11. AIR FLOW SYSTEM BLOCK DIAGRAM

All calculations were based on the above "worst" case steady flow conditions.

Consider Relative Humidity ( $\phi$ ):

$$\phi = .90 = \frac{P_{H_2O}}{P_{\text{sat at } 50^\circ\text{F}}} = \frac{P_{H_2O}}{.1781}$$

Pressure ( $P_{H_2O}$ ) exerted by the water vapor alone:

$$P_{H_2O} = .9 (.1781) = .160 \text{ psi}$$

$$\therefore P_{\text{air}} = 14.699 - .160 = 14.536 \text{ psi}$$

The specific weight ( $W$ ) of the air mixture constituents at  $50^\circ\text{F}$ :

$$W_{\text{air}} = \frac{P}{RT} = \frac{14.536(144)}{53.3(460+50)} = .077 \text{ lbs/ft}^3$$

$$W_{H_2O} = \frac{.1603(144)}{85.8(460+50)} = .00053 \text{ lbs/ft}^3$$

$$W_{\text{mix}} = .077 + .00053 = .07753 \text{ lbs/ft}^3$$

where:

$W$  = Weight of constituent  
 $T$  = Temperature in degrees Rankine  
 $R$  = Gas constant

At  $338^\circ\text{F}$ :

$$W_{\text{air}} = \frac{14.536(144)}{53.3(460+338)} = .04921 \text{ lbs/ft}^3$$

$$W_{H_2O} = \frac{.1603(144)}{85.8(460+338)} = .00034 \text{ lbs/ft}^3$$

$$W_{\text{mix}} = W_{\text{air}} + W_{H_2O} = .04955 \text{ lbs/ft}^3$$

Volume rate ( $\dot{V}$ ) of flow mixture into processor at a velocity ( $V$ ) of 50 ft/min:

$$\dot{V} = A_p V = 56,224 \text{ ft}^3/\text{hr}$$

where:

$$A_p = \text{Process Chamber Flow Area (18.74 ft}^2\text{)}$$

weight rate of flow ( $\dot{W}$ ) in the processor is:

$$\dot{W}_{\text{mix}} = W_{\text{mix}} \dot{V} = 2785.6 \text{ lbs/hr}$$

$$\dot{W}_{\text{air}} = 2766.8 \text{ lbs/hr}$$

$$\dot{W}_{\text{H}_2\text{O}} = 19.1 \text{ lbs/hr}$$

Computing the pressure loss at the various components of the air flow system (refer to Figure 12) starting with the inlet air path A-B, we have to find the hydraulic radius ( $R_H$ ) for the duct between fan and heat exchanger:

$$R_H = \frac{A_f}{S} = .2168 \text{ ft}$$

where:

$S$  = wetted perimeter

$A_f$  = duct flow area

Check Reynolds No.

$$N_R = \frac{4WVR}{u} = \frac{4R \dot{W}_{\text{mix}}}{u A_f}$$

$$N_R = 62,719 \text{ (turbulent flow)}$$

$\therefore$  assuming wall roughness ( $e$ ) = 0.00015

and  $f = 0.02$  for smooth pipes

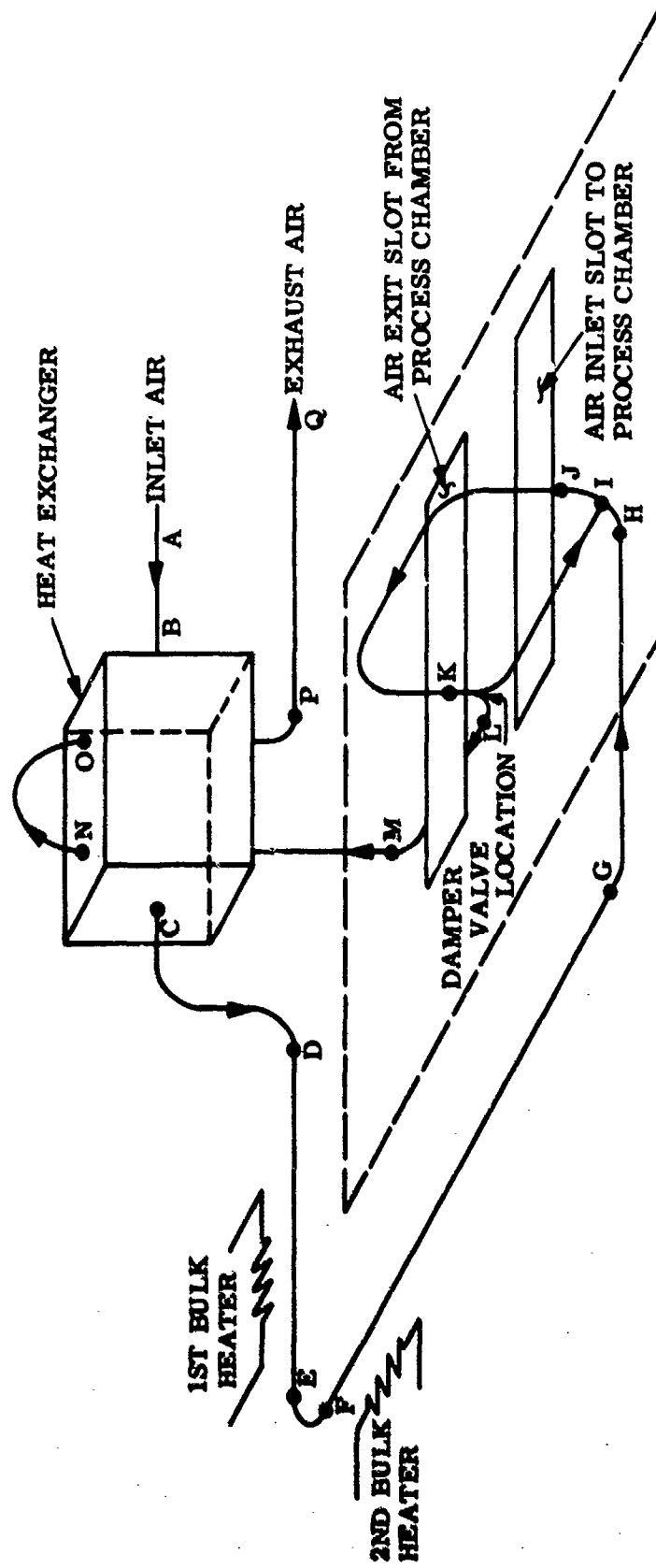


FIGURE 12. AIR FLOW ANALYSIS SCHEMATIC



$$\text{head loss (h)} = f \frac{1V^2}{D2g}$$

$$h = 0.1516 \text{ ft. of air mixture}$$

or:

$$h = 0.002 \text{ inch of water}$$

Head loss in the heat exchanger (Branch B-C):

$$\text{No. of tubes} = 264$$

$$\text{Tube ID} = 0.331 \text{ inch}$$

$$\text{Tube OD} = 0.375 \text{ inch}$$

$$L = 32.5 \text{ inch}$$

Hydraulic Radius:

$$R = \frac{A_f}{S} = 1$$

Check Reynolds No.

$$N_r = \frac{WVD}{u} = 11,202 \text{ (turbulent flow)}$$

$$\therefore f = 0.0275 \text{ (smooth pipes)}$$

$$\begin{aligned} \text{head loss (h)} &= f \frac{1V^2}{D2g} = 166.65 \text{ ft. of mixture} \\ &= 2.48 \text{ inches of water} \end{aligned}$$

Head loss due to entrance and exit losses:

$$h = \frac{K_o V_o^2}{2g} = \frac{(V_1 - V_2)^2}{2g}$$

$$h = 42.89 \text{ ft. of mixture}$$

$$= 0.638 \text{ inch water}$$

Head loss in the two bends between the heat exchanger and the first bulk heaters (Branch C-D):

$$h = 4f \frac{L}{D} + K_t \left( \frac{v^2}{2g} \right)$$

$$= 0.058 \text{ inch water}$$

Head loss through the first bulk heater (Branch D-E):

$$h = \frac{f l v^2}{D 2g} \quad W \left[ \frac{33.9 (12)}{14.7} \right] = 0.047 \text{ inches } H_2O$$

Head loss through the second bulk heater considering the increase in air temperature (Branch F-G):

$$h = 0.053 \text{ inch water}$$

Head loss from second bulk heater to oven inlet port (Branch G-H):

$$h = \left( 4f \frac{L}{D} + K_t \right) \frac{v^2}{2g}$$

$$= 0.062 \text{ inch water}$$

Head loss of transition into inlet bend (Branch I-J)

$$h = \left( 4f \frac{L}{D} + K_t \right) \frac{v^2}{2g} = .670 \text{ inch water}$$

Head loss through oven (Branch J-K):

$$h = 3.932 \text{ inches water}$$

Head loss at exhaust side of heat exchanger (Branch M-P):

$$h = 4.4 \text{ inches } H_2O \text{ (from manufacturer data)}$$

Head loss from exchanger to scrubber (Branch P-Q):

$$\begin{aligned}h &= \frac{f L V^2}{D 2g} \\&= 5.742 \text{ ft. of mixture} \\h &= 0.066 \text{ inch of water}\end{aligned}$$

Table I itemizes all pressure losses in the system. Adjusting the pressure losses to standard temperatures, we conclude that total system loss is 18.39 inches of water. Investigations towards locating a fan capable of delivering air at 1,000 cubic feet per minute (CFM) with a static head of 18.39 inches of water proved to require an enormous size blower. Consequently, it was decided to utilize two blowers in the system in a push-pull configuration. A New York Blower, Inc. Model 172 having a delivery capacity of 1,000 cfm at 8 inches of water static pressure was utilized at the intake side of the processor. A Dayton Electric Manufacturing Company blower, Model 4C131, with a 10 inch static pressure capability was selected for installation on the exhaust side of the processor. A negative pressure was created within the Processing Chamber resulting in a flow of ambient air into the film entrance and exit slots during operation. This prevented any of the fumes generated during processing from escaping into the work area. Actual tests demonstrated that this condition did indeed exist, and that the chamber was under continuous negative pressure.

Further test conducted after assembly of the unit indicated that air flow in the system was approximately 1,200 CFM versus the expected 1,000 CFM. This difference was attributed to lesser head loss than originally calculated and was utilized to apply a suction at the film exit slot and the Pre-heat roller enclosure. This suction ensured that any fumes emanating from either the film inlet or exit ports were indeed being exhausted to the Fume Scrubbing System.

## 6.2 FILM HEATING

Heating of the film within the processing chamber was accomplished by forced convection of heated air blown across the film. As shown in Figure 13, heated air is directed through a series of constant radius baffles to blow perpendicular to the film longitudinal axis. The continuous 50 feet per minute air flow velocity removed all processing by-products from the film surface.

TABLE I  
PRESSURE DROP MATRIX

Branch	Description	Calculated Head Loss ("H <sub>2</sub> O)	Characteristic Velocity (ft/sec)	Characteristic Temperature (°F)	Adjusted Head Loss ("H <sub>2</sub> O)
A-B	Blower to exchanger	0.002	11.27	50	0.001
B-C	Thru exchanger	3.120	63.29	50	3.001
C-D	From exchanger to 1st heater	0.058	17.47	180	0.070
D-E	Thru 1st heater	0.047	17.47	180	0.056
E-F	1st heater to 2nd heater	0.058*	17.47	260	0.078
F-G	Thru 2nd heater	0.053	17.47	260	0.071
G-H	2nd heater to transition	0.062	17.47	338	0.093
H-I	Transition	0.100*	8.85	338	0.150
I-J	Inlet bend	0.670	8.85	338	1.008
J	Inlet duct	0.187	8.85	338	0.281
	Bend	0.670	8.85	338	1.008
	Sudden enlargement	0.999	0.83	338	1.503
	Heat processor	0.001	0.83	338	0.001
	Sudden contraction	0.548	0.83	338	0.824
	Bend	0.670	8.85	338	1.008
	Discharge duct	0.187	8.85	338	0.281
	Bend	0.670	8.85	338	1.008
K	Outlet duct	0.670	8.85	338	1.008
K-L	Transition	0.100*	8.85	338	0.150
L-M	Outlet to exchanger	0.062*	8.85	338	0.093
M-P	Thru exchanger	4.40 **		338	6.622
P-Q	Exchanger to scrubber	0.066	36.96	212	0.083
					18.39

\* Estimate

\*\* Vendor prediction

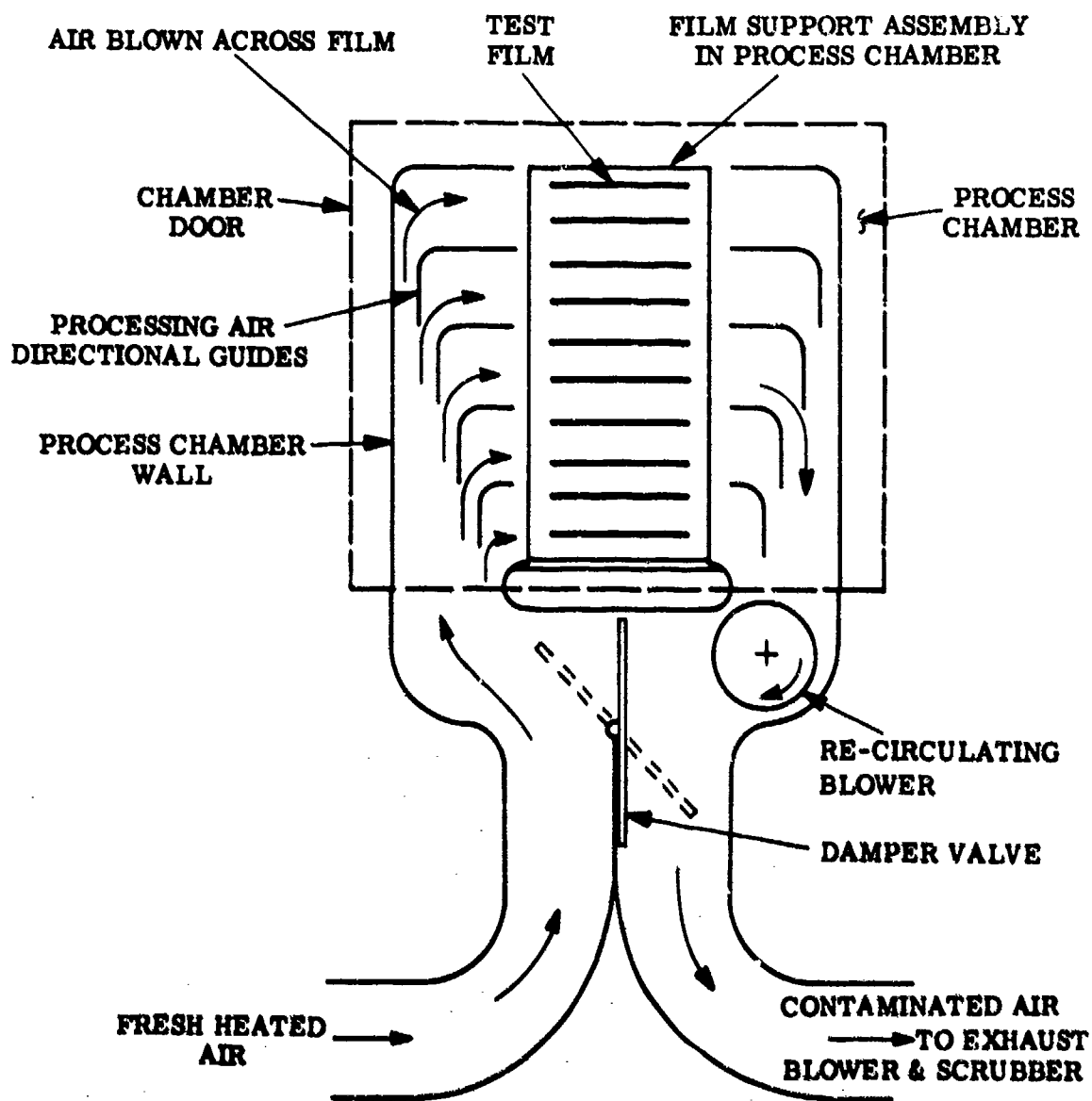


FIGURE 13. AIR FLOW PATH ACROSS FILM

Either full fresh air or partially recirculated air processing is available by the utilization of the Damper valve. When the valve is set in the vertical position, all hot effluent contaminated process air must exhaust. When the damper valve is adjusted for a circulatory mode, some of the contaminated air is mixed with the inlet air and a portion is exhausted. The amount of inlet air is adjusted to accommodate the percentage of fresh air requirement by adjusting the By-Pass valve (located at the inlet blower) in conjunction with the Damper valve.

### 6.3 FILM COOLING

Film is cooled upon exiting from the processor chamber by the use of forced convection blowers. The relatively short path between the exit slot and the capstan film drive required that four blowers each having 50 cubic feet per minute capacity be utilized. The blowers were arranged in groups of two in parallel such that one blower would direct an air blast to the film base and the other blower would cool the emulsion side. Ambient temperature air was utilized for cooling.

A cooling chamber covered the film exit slot to contain any fumes emitted by the hot processed film and to provide a receptacle for the cooling air being emitted from one pair of film cooling blowers. An exhaust pipe attached to the top of the cooling chamber allowed the incoming cooling air to be exhausted to the Dayton, Inc. exhaust fan at the output end of the processor. This gas was then directed into the Fume Scrubber.

The exhaust pipe leading from the cooling chamber to the exhaust fan was sized to evacuate 125 cubic feet of air per minute, thereby being slightly greater than the cooling air being introduced by the film cooling blowers. The remaining makeup air was derived from the film exit slot at the bottom of the shroud and some heated air from the processor. This balance provided a continuous negative pressure within the cooling chamber so that any residual fumes were continuously being exhausted and not allowed to enter the working environment.

The second set of cooling blowers were placed directly under the first set and directed down towards the capstan film drive. At this point the film was well scrubbed of processing gases by the first set of blowers, however, the air from the second set of blowers was allowed to be exhausted through the intake ports of the electronic chassis cooling fans and directed to a vent outside of the processing room. This effectively removed any remaining Iodoform vapors that could further contaminate the working area.

Thermocouples placed on the film emulsion during maximum processing speeds of 25 feet per minute showed that the film was cooled from the 170°C processing temperature to approximately 41°C before the emulsion contacted any

roller. Additional cooling was accomplished by conduction through the large capstan roller which further reduced the film temperature to near ambient conditions.

#### 6.4

#### VARIABLE AIR FLOW

Provisions in the design allowed for a by-pass valve to be installed between the main air-inlet duct and air exhaust duct of the processing chamber. This design included a Damper valve which by-passes air from the outlet of the main air-inlet duct directly to the air exhaust duct permitting the operator to adjust input air flow from 10 to 100 percent. This capability permits testing of the thermal processing film material under various concentrations of emitted processing gas to determine densitometric changes.

#### 6.5

#### AIR BAR

As discussed in paragraph 3.1, an air bar was utilized in the film transport design to enable the film to make a 90 degree turn from its input orientation. Incoming film is wrapped around the air-bar roller (which is set at 45 degrees relative to the inlet axis) thereby permitting a total 90 degree shift in film direction. The film is floated and supported by a layer of heated air as it slides around the skewed air bar thereby avoiding any physical contact with the air bearing. (As was discussed in paragraph 3.1, the film is transported into and out of the process chamber with the emulsion always away from possible contact with any surface or roller of the roller cage. Film support is always accomplished on the base side of the film thereby providing utmost protection to the film emulsion, since it must be remembered that the emulsion is very tacky and sticky at the processing temperatures and easily deformable).

Air delivery through the air-bar was accomplished by a series of slots located axially along the bar. A manually rotatable indexing mask mechanism located within the air-bar allowed the closing or opening of a predetermined number of slots proportional to film width. The slot discharge area was designed to be constant regardless of film width.

The air-bar design consisted of two tubes coaxially fitted to each other. The outer tube contained a series of approximately one-inch long slots located along its longitudinal axis. The machined slots were distributed along the surface area of the bar that would be encountered by the film path. Slot geometry was arranged in such a manner that regardless of film width the total slot area under the film in process was constant. This was accomplished by closing or exposing a pre-arranged number of slots dependent on film width. The second tube (mask) located within the outer tube contained a series of slots corresponding to a pre-set pattern such that when it was rotated about its axis it would

expose or block various slots of the outer tube dependent on the film width being processed. In practice, the operator adjusts the inner tube to a particular film width setting before film is processed.

#### 6.5.1 Air Flow Analysis

An analysis was performed to determine the pressure and volume of air required to successfully float the film at the air bearing. Complicating the air pump selection was the requirement to support the film throughout the required film tension range of from 0.25 to 1.25 pounds per inch of film width. The analysis, therefore, considered the air pressure and flow requirements for various radial clearances at the minimum and maximum tensions.

Pressure required for Equilibrium (see Figure 14):

$$\int_0^{\pi/2} p dA \cos \phi = T \sin \theta$$

$$\int_0^{\pi/2} P(r+h) \frac{S}{\sin \theta} d\phi \cos \phi = T \sin \theta$$

integrating and collecting terms:

$$P = \frac{T}{2S} \frac{1}{(.611 + h)}$$

To determine volume rate of flow:

$$\dot{V} = VA$$

$$= V \left[ \frac{2\pi p}{\sin \theta} = \frac{2S}{\sin \theta} \right] h$$

$$= \frac{V2h}{\sin \theta} \left[ \pi \frac{(r+h)}{2} + S \right]$$

$$\text{but } V = \left[ \frac{2g \Delta P}{W} \right]^{1/2}$$

substituting and rearranging terms:

$$\dot{V} = 10 \left[ \frac{2g}{W} \frac{T}{S} \frac{1}{(r+h)} \right]^{1/2} h \left[ \pi \frac{(r+h)}{2} + S \right]$$



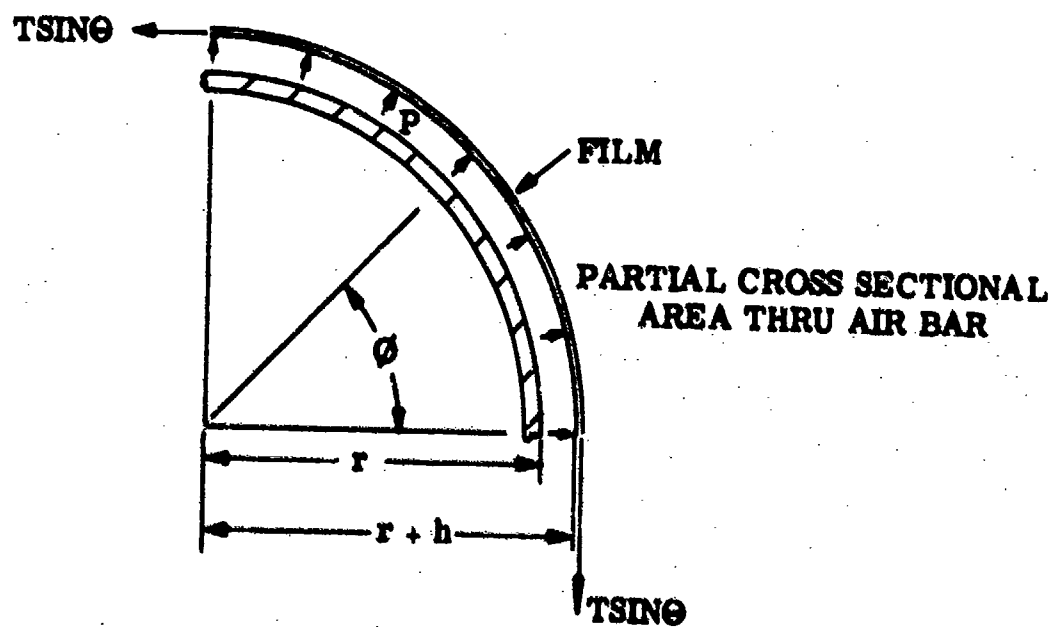
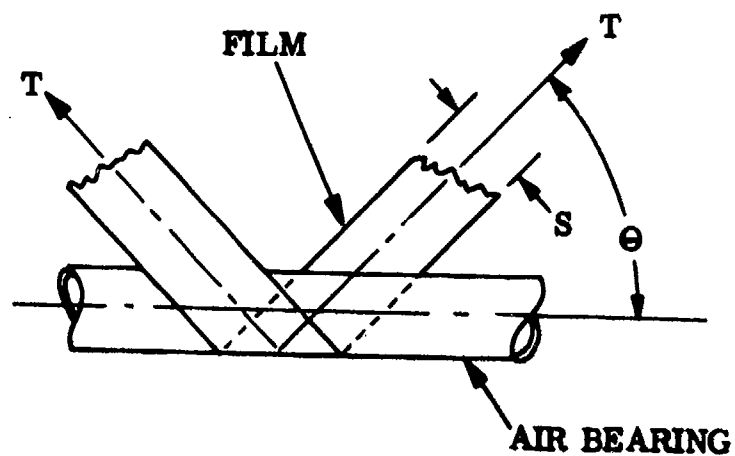


FIGURE 14. AIR BEARING ANALYSIS SCHEMATIC

where:

$\dot{V}$  = Volume rate of flow (ft<sup>3</sup>/min)

T = Film Tension (lbs)

W = Specific Weight of Air at 338°F (lbs/ft<sup>3</sup>)

S = Film Width (inches)

r = Air Bar Radius

h = Radical Clearance between Bar and Film (inches)

g = 32.2 ft/sec<sup>2</sup>

p = pressure (lbs/in<sup>2</sup>)

Solving the pressure and volume rate of flow equations for various radial clearances resulted in parametric curves being evolved and shown on Figures 15 and 16. These curves indicate the operating envelopes within which the air-bar pump has to operate. Schedule constraints and availability resulted in the selection of a Gast, Inc. Model SV180, air blower having an air delivery of 170 CFM at 3 pounds per square inch pressure. A bleeder valve was inserted in the air delivery system to reduce flow to the desired amount. Film tracking tests indicated that by setting air flow to accommodate the maximum tension and film width it was not necessary to manipulate the bleeder valve to balance pressure and air flow for the various films and tensions. This resulted in reducing the number of operations and procedures required by the operator.

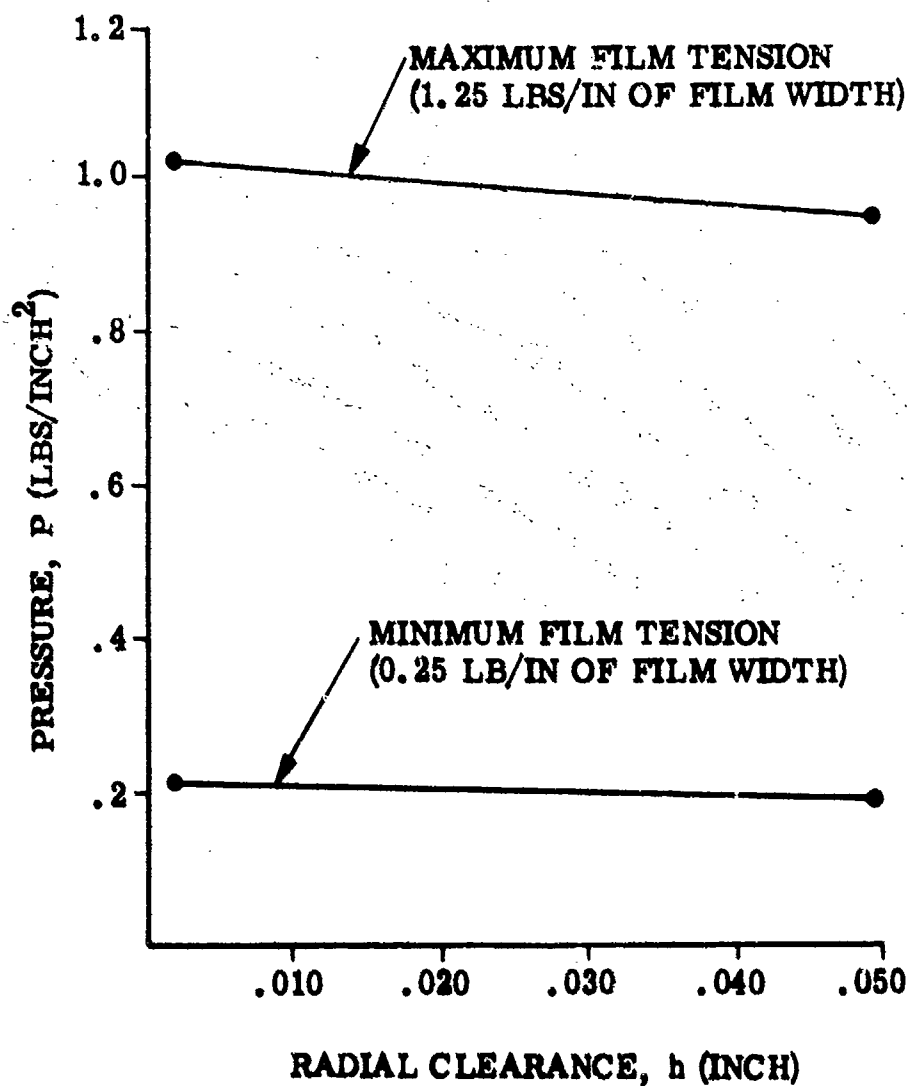


FIGURE 15. PRESSURE REQUIRED BETWEEN AIR-BAR AND FILM

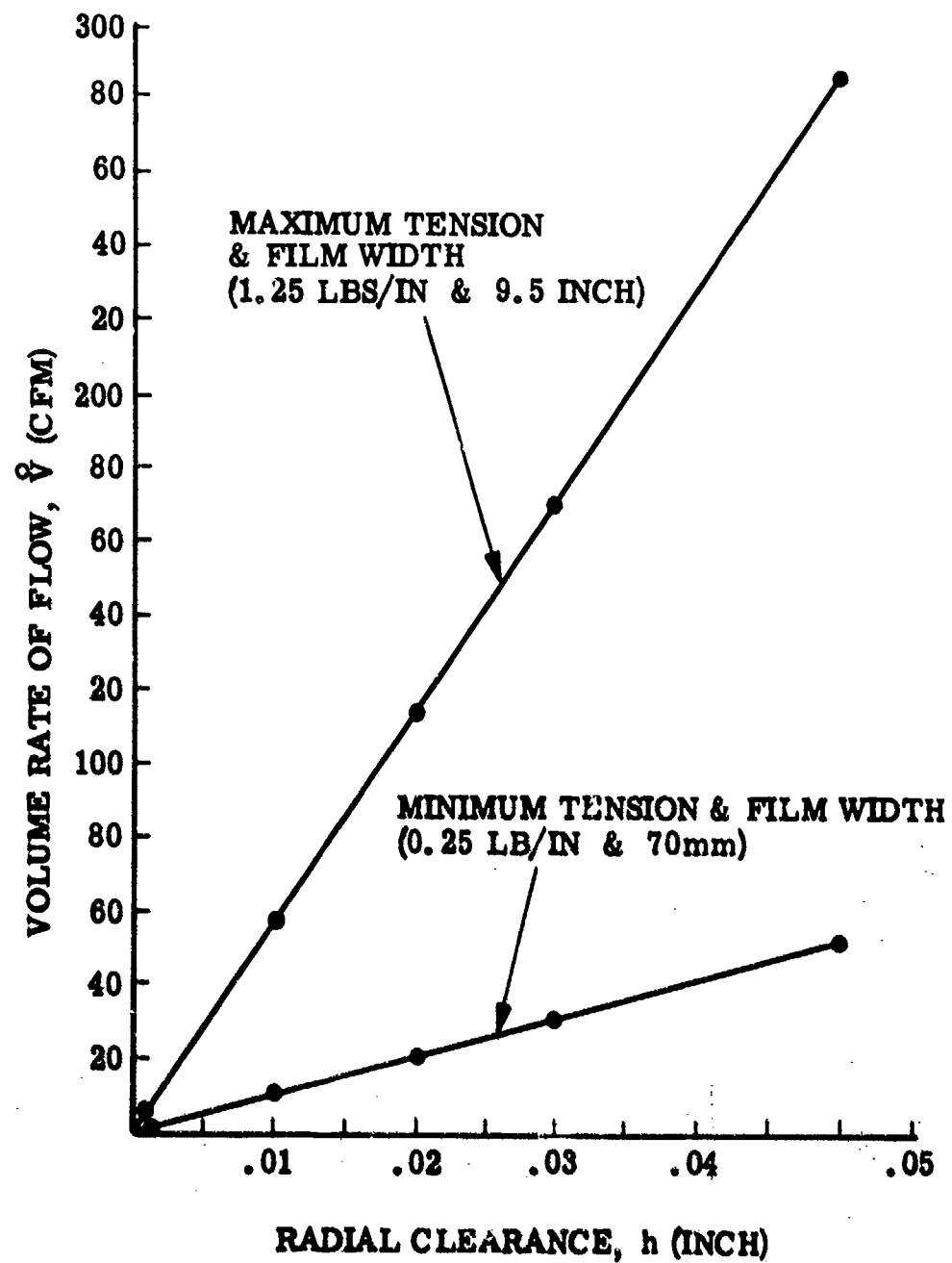


FIGURE 18. VOLUME RATE OF FLOW REQUIRED BETWEEN AIR BAR AND FILM

## SECTION VII

### AIR FILTERING SYSTEM

Free Radical type 2000 film, upon being processed, emits a mixture of gaseous effluents of which the primary constituent is Iodoform. To avoid and or minimize atmospheric pollution, the exhausted gas must be filtered. One method of filtering the exhaust is to evacuate the effluent through activated charcoal filters. This method suffers from some shortcomings in that (a) the incoming air must be cooled to less than 55°C to obtain maximum filtering efficiency, (b) it requires a continuous supply of activated charcoal filters to support the filtration process and (c) filters require frequent analysis to maintain adsorption at maximum efficiency. The need for continuous filter re-activation is costly and necessitates constant logistics to maintain an adequate supply. The need to reduce the air temperature to 55°C from the discharge temperature of 77°C necessitates further complexities in the design with higher operating cost to the user agency. Consequently, the use of an activated charcoal filter was deemed less desirable than a unit not requiring logistic support. An aqueous fume scrubber was used to satisfy this requirement.

A Norton Cyclonaire packed bed Fume Scrubber having a 1,200 cubic foot per minute (CFM) discharge capacity was utilized as the filtering agent. This unit is a standard device produced by the Norton Chemical Process Products Division located in Akron, Ohio. A block diagram of the Scrubber is shown in Figure 17.

The Cyclonaire unit is a counter-current, wetted bed fume scrubber. Polluted and fume laden air is drawn into the unit through an intake duct near the bottom of the tower and moves upward through a bed of 2 inch plastic Intalox saddles. This air is discharged into the Scrubber by the exhaust blower of the Processor.

The packed bed is triggered by water sprayed from a rigid poly-vinyl-chloride (PVC) manifold. This manifold is specially designed to assure complete and uniform wetting of the packed bed. As fume laden air travels through the packed bed, it is scrubbed by the downcoming liquid which causes the gaseous Iodoform to solidify into flakes and also to absorb other by-product gases.

A dry bed of packing above the distributor functions as a separator to remove entrained water from the air before it is discharged into the atmosphere.

The housing, exhaust blower assembly, impeller, hold-down and support plates of the Cyclonaire are manufactured from fiber-glass-reinforced vinylester. The

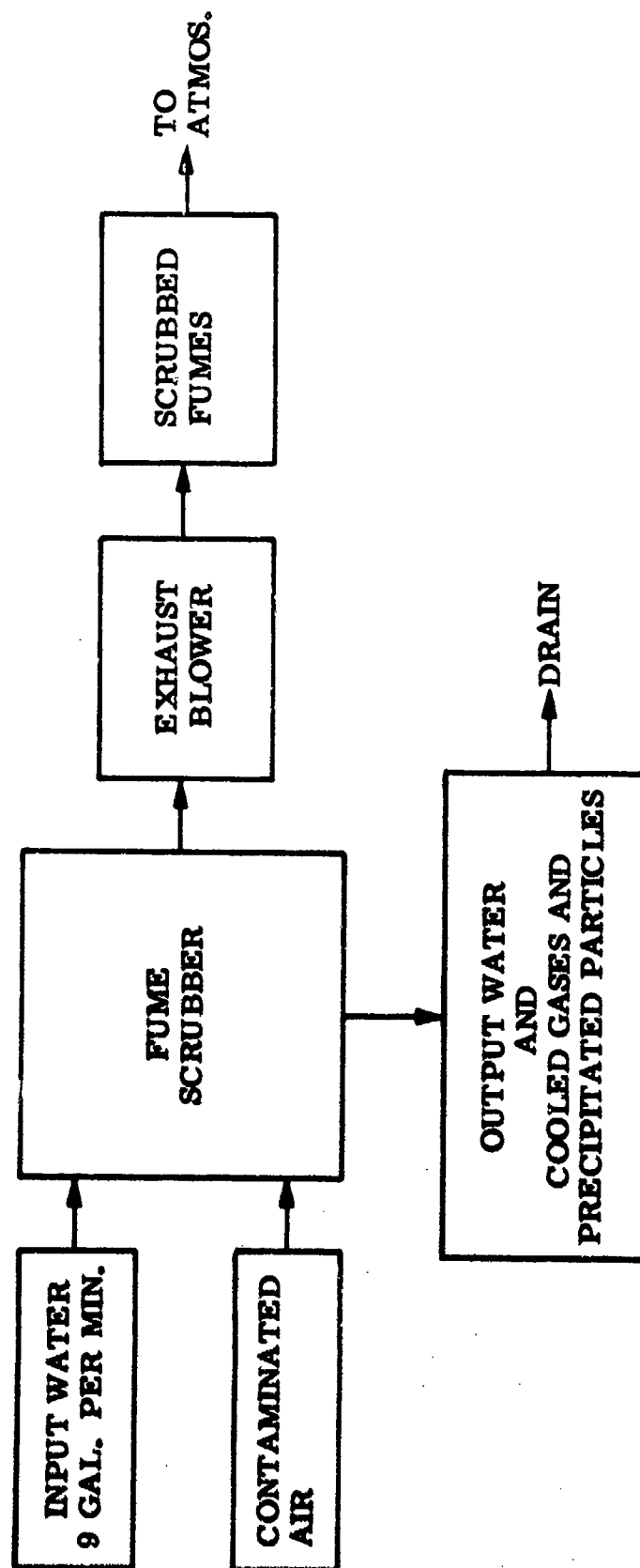


FIGURE 17. FUME SCRUBBER BLOCK DIAGRAM

distributor is constructed of rigid PVC, while the plastic saddles are fabricated of polypropylene to withstand the high temperature (77°C) inlet gas emitted from the Processor unit. The utilization of fiberglass and other plastics in the construction of the scrubber components combine excellent corrosion resistance with high strength and light weight making them suitable for indoor or outdoor installation. Fouling resistance and operational life of the plastic saddle packed bed is virtually unlimited.

Water requirements for irrigating the packed bed is supplied by a filtered 9 gallon per minute source. Discharged water can either be drained into a sewer (as was done at conclusion of the program) or recirculated through a filtering tank to capture the solid flakes of Iodoform being scrubbed from the exhaust gas.

## SECTION VIII

### LUBRICATION CONSIDERATIONS

The need for high processing temperature (170°C) required that particular consideration be given to rotational components within this environment. Specifically, the bearings of the Roller Frame Assembly, Circulating Blower and the Pre-heat Roller required special attention.

A design analysis and discussions with the McGill Bearing Corporation and Fafnir Bearing Corporation indicated that bearings having special heat treatment and ball sizing were necessary to operate successfully in the environment. The computed radial loads and low operating speeds of the Roller Frame bearings resulted in utilization of permanently sealed and shielded bearings having an estimated life expectancy of approximately 15,000 hours. Additionally, the low speeds and loads of the Pre-heat Roller bearings were in the same category and would display a reasonable life, however, these bearings were not available as shielded units and were packed with high operating temperature grease.

An examination of the bearing lubrication requirements for the Circulating Blower resulted with the bearing manufacturers agreeing that due to the relatively high speed (1,725 rpm) and high operating temperature (although bearing loads were low, approximately 1.5 lbs per bearing) it would be necessary to periodically re-lubricate the bearings to achieve a reasonable life cycle. Breakdown and oxidation of the lubricant was the primary cause for concern. To achieve maximum bearing life, the design allowed for lubrication fittings to extend into the bearing housings thereby providing a means for lubricant replenishment. A heat stable silicone grease (Dow Corning No. 44) was chosen as the lubricant for these bearings and the Pre-heat Roller bearings. Lubrication fittings were also provided on the Pre-heat Roller bearings to extend their life cycle. It is anticipated, based on conversations with the bearing manufacturers, that life expectancy of up to 3,000 hours can be anticipated for the high speed bearings and well over 5,000 hours for the Pre-heat Roller bearings.



## SECTION IX

### ACCEPTANCE TESTING

Final Acceptance Tests were performed at the user's facility with Pre-Acceptance Tests performed at FSDS/Syosset, New York.

#### 9.1 ACCEPTANCE TEST RESULTS.

Results of the Acceptance Tests are summarized below:

<u>Test</u>	<u>Results</u>
Mechanical and Visual	
Dimensions	Within Specifications
Marking	Acceptable
Workmanship	Acceptable
Tension Control Verification	Within Specifications of 0.25 to 1.25 lbs/inch of film width
Fresh Air Makeup Verification	Not verified - data accepted as shown in the Operating Manual
Film Transport	
Spool Accommodation (all sizes)	Satisfactory
Film Tracking/Velocity/Tension (All sizes at high and low ranges)	Acceptable, all within limits and $\pm 1\%$ tolerance
Temperature Control System	
Low Temperature Stability	Acceptable, standard deviation was $\pm 0.72^{\circ}\text{C}$ over a six hour period

<u>Test</u>	<u>Results</u>
Temperature Control System (cont.)	
High Temperature Stability	Acceptable, standard deviation was $\pm 0.83^{\circ}\text{C}$ over a six hour period
Film Processing	Acceptable - leakage of processing by-products into the operating environment was found to be acceptable, however, Iodoform could be detected in the exhaust air stream. It was determined that the fume scrubber removed approximately 84-86% of the Iodoform from the exhaust gases. Further increase in efficiency might be expected from further refinement of the exhaust scrubber system.
Thermal Impact	Acceptable

## 9.2 CONCLUSION

The Free Radical Film Processor, Model F-1001, delivered under the terms of this contract fulfilled all the technical requirements of the subject program and no desirable technical improvements were immediately apparent. The processor will provide a highly flexible and precise instrument for the testing and evaluation of Free Radical and other Heat Processed Duplication Films. It may be used to determine the effect of temperature, processing time, processing air flow rate and processing air purity on the sensitometric and other photographic characteristics of the test film. It will also provide design data for the development of any second generation heat processing equipment that would be required.

However, while the scrubber system performed in accordance with Environmental Standards the design could be improved to reduce the quantity of effluent gasses and other waste products discharged to the environment. Specifically the particulate waste material could be filtered from the scrubber water for more efficient disposal. The scrubber water could also be cooled and reused in succeeding scrubbing cycles at a considerable savings in required water supplies. The gasses that exit the scrubber tower could be further "polished" to further reduce the amount of chemical vapors that are discharged into the outside environment.

The Model F-1001 Free Radical Heat Processor should now be run for a considerable period of time over its full processing range to determine the effective range of those parameters which are important to the sensitometric performance of the heat processable materials. Based on the evaluation of this data the necessary dynamic range of a practical operational machine can be established. This analysis could lead to the design of a significantly simpler machine with reduced but adequate capacity and flexibility to accomplish the desired film processing.

The fume scrubber system efficiency should also be increased to improve the gas absorption by the scrubber liquid. This could involve change in the scrubber tower dimensions, packing material, scrubbing liquid, and or the installation of an additional filter of the activated charcoal type to further increase extraction efficiency for waste gasses, particularly Iodoform.

In large scale heat processing installations it is recommended that a filter press be installed in the water circulation part of the scrubber system to remove the precipitated Iodoform crystals from the water before the water is discharged to the waste line or is recirculated. This will result in the collection of the waste Iodoform in a highly concentrated form for more efficient disposal. The water filter system will also reduce the disposal load on the installation sanitary waste facilities.

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13. ABSTRACT <p>Development of a Free Radical Film Heat Processor provided an accurate test bed for the determination of processing requirements for Free Radical Film Materials. The device consists of two units: a Processor and a Fume Scrubber. The Processor permits film rolls, ranging from 70mm to 9.5 inches wide, to be subjected to any desired processing temperature between 100 to 170°C at processing speeds from 5 to 100 feet per minute. At 25 feet per minute the 75 foot processing film path length permits a three minute processing time. Film tension can be controlled when processing at 25 feet per minute or less at any incremental setting between 0.25 to 1.25 pounds per inch of film width. Additional capability allows high speed film transport between 25 and 100 feet per minute. Processing byproducts emitted by the Free Radical materials are filtered and almost completely removed from the hot processing air by an aqueous fume scrubber.</p> <p>The equipment will be used to test and evaluate Free Radical and other heat processed duplication films. It will also provide design criteria for the development of any necessary second generation processors.</p>			

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